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CATGUT ACOUSTICAL SOCIETY, INC.

The Catgut Acoustical Society is a group of people interested in the support and development of new musical instruments and improvements of existing instruments. In recent years it has become possible to apply scientific knowledge, acoustical principles and testing methods to these ends.

The Society provides an opportunity for professional workers and interested laymen to participate in its program. Among the former are performing musicians, musicologists, instrument makers, composers, scientists and engineers whose disciplines are pertinent to the furthering of this work.

The Society is best known for pioneer work in research and application of scientific principles in the making of conventional and new instruments of the violin family. Projects include studies of the properties and behavior of materials used in instrument construction, such as wood and varnish, and the effect of environmental conditions on tone quality. The Society also supports publications, musical compositions, lectures and concerts.

Members receive the semi-annual JOURNAL of the Society and other publications of interest from time to time. The Society promotes active collaboration among research workers and dissemination of information throughout the world. Correspondence and informal meetings among the membership are encouraged. Articles on appropriate subjects are welcomed for the JOURNAL.

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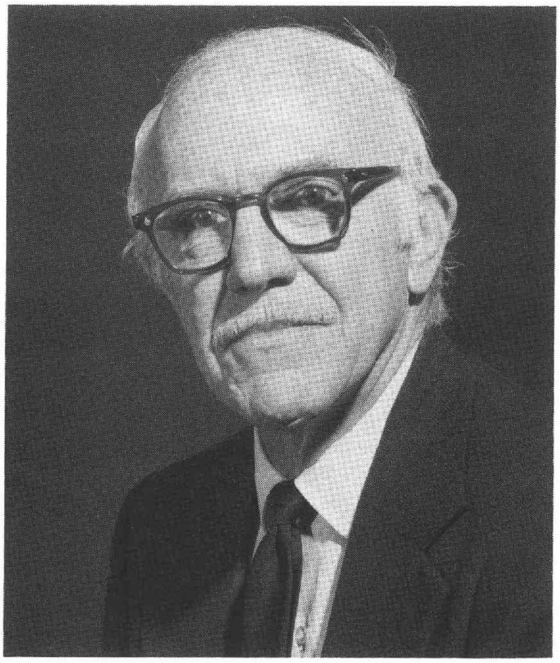
THIS ISSUE OF THE JOURNAL OF THE CATGUT ACOUSTICAL SOCIETY, INC.

IS GRATEFULLY DEDICATED TO

ROBERT EDWARD FRYXELL 1924 - 1986

CHEMIST, CELLIST, FAMILY MAN AND FRIEND EXTRAORDINARY



It was with shock and a deep sense of loss that we learned of the death of Robert Fryxell, our Editor of the Journal of the Catgut Acoustical Society, at the age of 62 on December 22, 1986.

Robert was a chemist at the General Electric Company where he had been employed since the 1950s. He was a native of Moline, Illinois, held a bachelor's degree in Chemistry from Augustana College and received his doctorate in Chemistry from the University of Chicago. He was one of the founding members and also an early president of the Catgut Acoustical Society. For the past 23 years he edited and published the Society's "News Letter" which was upgraded to be the Society Journal three years ago.

Robert was a cellist and chamber music was a major interest of his. He was one of the founding members of the Amateur Chamber Music Players and served on the faculty at the Pittsfield Music School in Massachusetts.

On the evening of July 21, 1986 at the CAS Hartford Symposium, the Trustees of the Society presented Robert with a certificate which summarizes his contribution to the Society. It reads:

"This certificate is presented to Robert Edward Fryxell in appreciation of his central role in creating and maintaining a communication channel for an international community of investigators and practitioners of the arts, science, and crafts of violin design and construction.

Bob has demonstrated an understanding of the communication this community needs, a dedication to countless hours of building an excellent newsletter and journal at minimum cost, a broad knowledge of the field and the meticulous skills required of a technical editor.

He has set an example of editorship which is both a challenge and an inspiration."

We are all exceedingly grateful for all that he has done for this Society.

Robert M. Meyer

ACHIEVING AN AIR/BODY COUPLING IN VIOLINS, VIOLAS AND CELLOS: A PRACTICAL GUIDE FOR THE VIOLIN MAKER

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A vibrational mode of the wood of the whole violin, including neck, fingerboard and body, called BO mode, can be adjusted to have the same frequency as the Helmholtz "air" mode of the body cavity, called AO mode[1]. After matching the frequencies of the AO and BO modes on over 60 instruments, including modern as well as old Italian and French violins, violas and cellos, I have come to the conclusion, as has everyone I know who has heard the results, that each of the instruments was not just improved, but often dramatically improved by achieving a wood/air frequency match or coupling.

In general, the bigger the original mismatch between the AO and BO frequencies, the bigger the change in sound when these modes are matched. However, there are often dramatic changes when the mismatch is only a semitone or less. It is my experience that in every case the newly matched instruments sound more open and more resonant than they had previously. The depth and quality of sound is also improved and in many cases the power increased as well.

CHANGING THE WOOD (BO) FREQUENCY

If one were to clamp a stick of wood somewhere along its length and set an end of the stick in motion, the motion of the end of the stick (A) (fig.1) would vibrate up and down with a certain periodic speed (frequency). If weight (mass) were added to the moving end (A), the stick would move more slowly, i.e., the frequency would decrease.

If one shaves off wood in section (B) (fig. 1) where the wood is bending, the wood becomes less stiff and won't have the spring needed to maintain the same frequency.

So one can lower frequency by adding mass at the moving area (A), or by removing stiffness at the bending area (B). Conversely, adding stiffness (by adding more wood) in the area (B), or subtracting mass (by removing wood) in the area (A), will raise the frequency. (Figure 1).

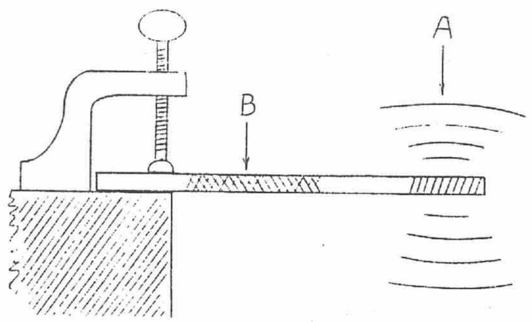

Fig. 1. Stick clamped at one end. (B) bending area; (A) moving area.

The neck, scroll, and fingerboard of an instrument are analogous to the stick example. The entire neck and most of the length of the fingerboard, except for approximately the last 25mm at the wide end, are bending as in area B. The section comprised of the last 25mm or so at the wide end of the fingerboard is analogous to the area (A) and is moving up and down. The scroll is also somewhat analogous to section (A), but requires a greater change in mass to effect a change in frequency. The chinrest area around the lower block of the instrument is also analogous to section (A), but again requires a greater mass change than does the end of the fingerboard in order to cause a frequency change.

Figure 2 illustrates the motion of the entire violin in the BO frequency range. Note the nodal lines (areas of no movement).

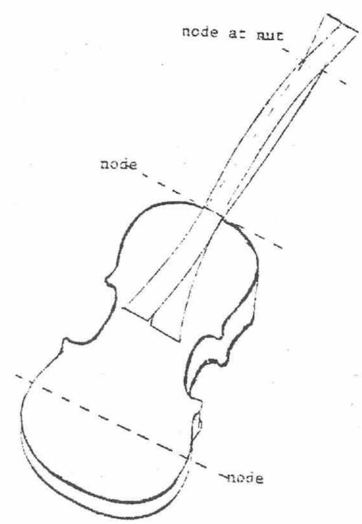

Fig. 2. First bending of neck, rigid body pitching of corpus and bending of body. Thickened lines of body and phantom drawing of other parts are an attempt to show vibration of body, bending of neck, and vibrating of scroll and free end of fingerboard (not to scale {after Hutchins (1)}).

Now that we know from modal analysis studies[2] how the violin vibrates, application of the principles of simple physics as described above enables the violin maker to raise or lower the BO body frequency in order to match the AO air frequency and achieve or maintain optimum sound. All of this can be completely or mostly done by working with the fingerboard, and in every case without altering the basic integrity (plate graduations) of the instrument.

HOW TO DO IT

To begin the process of mode matching, the instrument must be tested to determine the present pitches of the AO and BO modes. First, test the instrument while it is completely set up and under full string tension, as it would be for playing. One should hold the instrument at a node (a non-moving part - see fig. 2) and tap on a moving part such as the back of the scroll or the end of the fingerboard. Listen to the resulting pitch, which is the BO note.

For violin and viola, I hold the instrument on the purfling at the widest point of the lower bout with the scroll pointing toward the floor. I rest the strings of the instrument lightly against my shirt to damp them and prevent their vibrations from interfering. Then I tap the back of the scroll with my fingertips to determine the pitch. For cello, I extend the endpin to playing position, hold the instrument at the nut, and tap the wide end of the fingerboard. It is helpful to damp the strings by threading a strip of flexible leather through them. Cello pitches can be trickier to hear, and so I often check them by feeling the body of the instrument vibrate as well. To do this, I suspend the cello from a strong fishline under the chin of the scroll where there is a node (fig.3), looping the line from behind the chin so it comes over the top of the nut. I recommend the use of a second, slack safety line which is looped loosely under the scroll above the peg box.

The belly of the suspended cello should be in front of a speaker which is connected through an amplifier to a sine wave generator. The frequency of the generator is then varied until one feels the wide end of the fingerboard vibrate. This is the BO frequency.

Once the BO frequency is established with the instrument set up under tension, then one should determine the AO frequency under tension as well. On violin and viola, I usually sing into the f-hole. By gliding the note up and down, I vary the pitch until I hear the instrument cavity resonate and feel the vibration by placing my fingertips gently on the back. The response of the instrument is usually quite obvious. I double check by blowing gently through an f-hole to be sure the pitches agree. Blowing too energetically will elevate the pitch. I also check both f-holes for agreement.

For cellos, I am unable to sing a low enough pitch, although men with low voices seem to have no problem. I blow gently into an f-hole, aiming the flow of air toward the opposite f-hole, and listen to the pitch produced. For the AO mode, I also suspend the cello in front of a loudspeaker connected to a sine wave generator. When the appropriate AO frequency is played through the speaker, I can feel the instrument vibrate. I usually stand with the cello between my body and the speaker, and by reaching around the cello and touching the belly with my

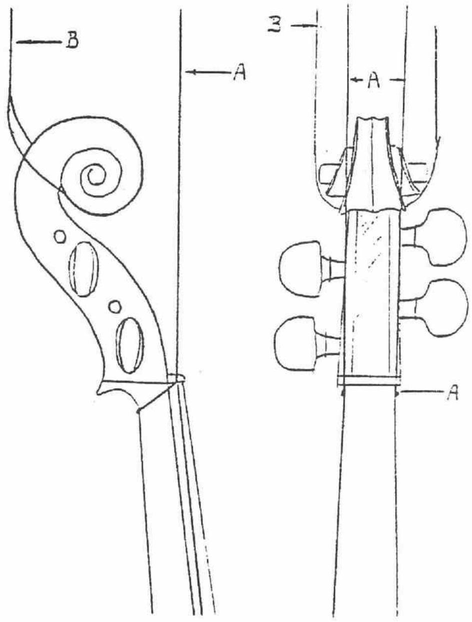

Fig. 3. Suspension of cello at node line. The instrument is held up by a suspension line, (A). A safety line (B), is slung just below the scroll.

fingertips I can feel the vibrations readily when the correct frequency has been found.

The pitch obtained by blowing through the cello f-hole often seems to be slightly higher (¼ to ½ a semitone) than the AO pitch obtained by either singing into the cello cavity or by vibrating the cello with the sine wave generator and loudspeaker. I find that the lower pitch obtained by singing or by the sine wave generator is the better pitch to use when matching the AO/BO modes.

Once the AO and BO frequencies are established with the instrument under full tension, repeat the same procedure without the bridge and strings in place. Be sure, on violins and violas, that the endbutton is in, the chinrest is on, the pegs are seated, and the soundpost is snug. On cellos, be sure the post is secure, the pegs are in, and the endpin is extended to playing position. The pitches of the modes are usually the same whether the instrument is under string tension or not.

The only times I've not gotten the same AO and BO pitches under tension and not under tension was when the soundpost was loose or the top of the instrument was unusually thin. Because the frequencies do not change substantially upon the release of tension, the violin maker can check the AO and BO frequencies as he or she works without the necessity of setting up the instrument and taking it down each time.

TO LOWER THE BO MODE

Once the pitches are established, the violin maker must decide how best to achieve a mode match. Lowering the BO mode can be achieved by:

1) extending the length of the hollowing underneath the fingerboard toward the neck joint (fig. 4). One may also deepen the hollowing under the fingerboard, thereby making the fingerboard thinner;

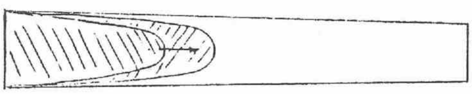

Fig. 4. Extension of the hollowing of the undersurface of the free end of the fingerboard to reduce the BO mode frequency (not to scale).

2) planing the fingerboard from the top. Most of the wood to be removed is the wood over the neck. Thus, the nut end of the fingerboard will have more wood removed than will the wide end (fig. 5);

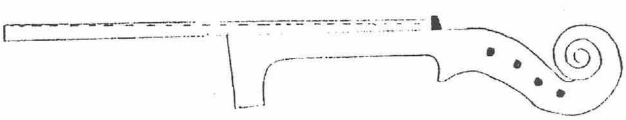

Fig. 5. Reduction of fingerboard thickness in lowering BO frequency. Note that greatest removal of wood is toward nut end of fingerboard.

3) installing a heavier chinrest. For example, replacing a light boxwood chinrest with a chinrest of heavy ebony with Hill-style feet can lower the BO mode as much as a semitone;

4) by replacing boxwood or rosewood pegs with heavier ebony pegs;

5) by putting on a longer fingerboard.

In order to extend the hollowing underneath a fingerboard (fig. 4), one can either remove the fingerboard (a job I prefer to avoid if possible), or one can use special incannel and back-bent gouges on long metal shanks, being very careful to protect the top of the instrument from damage. Design and development of appropriate tools for this work are currently in progress.

If the fingerboard has ample thickness, I often opt to plane it heavily (e.g.,more than half a millimeter - fig. 5). During the planing, it is imperative to check the pitches often. A rough guide on judging dimensions is that for every 3/4 of a millimeter removed from the narrow end of the fingerboard on violins and violas, a drop of about a semitone can be expected. Because the density and stiffness of ebony varies, this is only an approximation.

Instruments with major mismatches (a minor third or more) may require a combination of methods. Be sure to chamfer the edges of the fingerboard before checking the final pitches on the way to achieving a match. Chamfering the wood increases flexibility (i.e., lessens stiffness) and may noticeably lower the body frequency (BO) particularly on the cello.

If I elect to fit a new fingerboard on an old viola or cello, or am fitting a fingerboard to a new viola or cello, at first I do not shorten the fingerboard at all. The extra length may be useful to lower the BO mode. The fingerboard can always be shortened to the traditional 5/6 of the string length once one is certain that the extra length is not required. I should note that the extra fingerboard length is disturbing to some cellists.

TO RAISE THE BO MODE

If it is necessary to raise the pitch of the BO mode in order to achieve air/body coupling, one may:

1) remove wood underneath the wide end of the violin or viola fingerboard for a distance of about 20mm in from the end, and for cellos about 40mm in from the end. The closer to the end of the fingerboard the wood is removed, the greater the effect;

2) install a lighter chinrest or lighter pegs;

3) shorten the fingerboard if its length permits.

In cases where the BO mode needs to be raised more than a whole step, or the fingerboard is already thin, I sometimes:

4) put on a new, thicker fingerboard.

OTHER COMMENTS

1) It is my experience, the AO frequency in violins is often found within a semitone of the note C (~262Hz). The AO in medium to large violas is often within a semitone of A (220Hz) or A^b (207Hz). The AO pitch of a small viola is likely to be higher, around B (247Hz) or B^b (~233Hz), and the AO pitch of a very large viola may be found around G$^\#$ (207Hz) or G (196Hz). In cellos it is often found within a semitone of F$^\#$ or G (92-98Hz). There are exceptions. This is intended to serve as a general guide of where one might start checking for the AO pitches.

2) It is often the case that once an instrument is AO/BO matched, the optimum soundpost position is different from the position before the matching.

3) Most shoulder rests do not appear to change the AO/BO modes. This may be because they span roughly across a BO node line (a non-moving part).

4) Be sure to check the AO and BO modes with the instrument under full tension before calling the mode matching work complete.

5) A little DoorEze (a stick lubricant available at hardware stores) on the tip of a pencil can be worked into the grooves of the nut and bridge. This is helpful to keep from shredding the strings and wood when taking the instrument down and setting it up for adjustment. Applying Doorreze to the saddle is helpful to keep it from being pulled up and out during these sessions, especially for cellos.

6) If it appears that there are two AO pitches on a large viola (a slightly lower one in the lower bout), the best results will usually be obtained by using the lower pitch as the AO frequency.

7) Cello fingerboards which have a flat surface beneath the C string also have a longitudinal ridge which increases the stiffness of the fingerboard and neck. The BO mode may be lowered further by planing off this ridge and converting the cello fingerboard to a round style, like a violin fingerboard.

8) To find the transition point from a moving area to a bending area on a cello fingerboard, place a lump of plasticene clay at the wide end. Move the clay away from the end in small increments and test the BO frequency after each move. The transition occurs at the point where the BO frequency is no longer lowered by the presence of the clay mass.

9) Last, but not least, wood changes to some extent in both frequency and compliance as it takes on water (humidity) or dries out. This fact may cause the relative relationships of the AO and BO modes to change slightly from season to season. It is advisable to do mode matching in a median condition under which the instrument is most likely to be played. For example, in Washington, D. C. I try to do mode matching in the spring or fall, or in air conditioned surroundinga during the summer. Further studies on the effects of humidity on the modal relationship are being conducted and will be published at a future date.

In conclusion, I have found these mode matching techniques to be a major breakthrough in achieving the very best instrument adjustments possible. Matching modes may not make a bad instrument into a good one, but it may make an unmatched instrument of any kind a better one -- and often a much better one!

REFERENCES

1. Hutchins, C.M., "Effects of an Air-Body Coupling on the Tone and Playing Qualities of Violins," Journal Catgut Acoust. Soc. #44, pp. 12-15, November, 1985.

2. Marshall, K.D., "Modal Analysis of a Violin," Journal Acoust. Soc. Amer. 77(2), pp. 695-709, February, 1985.

NOTE ON "BITRI OCTAVES" TUNED VIOLINS

Sie Anton
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Following my previous article in Journal # 46, I should like to add a short note concerning three violins that I have made recently. The plates of these violins have been tuned as follows:

The frequencies of the modes #1,#2 and #5 of the top and modes #2 and #5 of the back are in harmonic series with matching frequencies for the corresponding modes, or simply called "Bitri Octaves" matching.

Their frequency's values are listed in the following table:

No.	Year	Top			Back	
		+mode #1	X mode #2	O mode #5	X mode #2	O mode #5
61	1986	92Hz	185Hz	370Hz	185Hz	370Hz
63	1986	88	176	360	180	360
64	1986	85	173	355	178	355

These three Bitri Octaves tuned violins (Anton, 1986) have tonal qualities not only equal to the Double Octaves tuned violins, but also have prominent behaviour: Stronger resonance and more sensitive response compared to those of the corresponding Double Octaves (e.g. for the same frequency level). Some players who have tried them said: "The sound 'boils' in the forte and is 'silky' in the piano, ... endless energy..." In other words, they are easier to play, sweet but powerful, solid yet with woody timbre.

More experiments should be done for further confirmation of this behaviour in the "Bitri Octave" violins.

Reference:

S. Anton, "Comment on the "Double Octaves" Tuned Violins," CAS Journal #46, Nov. 1986.

Acknowledgement:

The author would like to express his appreciation to violinist Mr. Ngai Hau-Chau for his kind support in testing the violins keenly in every detail with various bowing dynamics, during several valuable discussions and collaborations.

FINITE ELMENT MODELING OF VIOLIN PLATE VIBRATIONAL CHARACTERISTICS

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ABSTRACT

Natural frequencies and mode shapes for violin back and top plates have been obtained using finite element analysis. The computer model was based on an actual violin, and results compare well with holographic experimental results.

INTRODUCTION

Much attention has been given to the vibrational properties of violins in an effort to improve their design and analyze why certain violins have better musical qualities than others. These studies have generally been experimental in nature. In a 1981 article in Scientific American, C. M. Hutchins[1] thoroughly surveyed the efforts of researchers in this area over the last thirty years. Laboratory techniques have been developed which enable the experimentalists to determine the natural frequencies and mode shapes of the top and back plates of a violin, as well as the vibration properties of the violin as a whole.[2] K. Marshall[3] used a computer animation technique to clearly demonstrate the various mode shapes on film.

A fundamental question, as stated in Reference 1, remains: "Although the knowledge of certain characteristic relations in the eigenmodes and eigenfrequencies of free violin plates makes possible the construction of consistently fine instruments, it does not explain what happens to those modes when the plate pairs are assembled into the extremely complex vibratory system of the completed violin".[1] Thus, it would be desirable to find direct relationships between the vibrational characteristics of the separate plates and the violin as a whole. It would be especially useful to be able to change the vibrational characteristics of the plate in various specific ways, and determine how these changes would effect the properties of the entire violin.

In recent years computer modeling has been approached as a way of dealing with these questions. Finite element analysis, in particular, has been useful since it enables the researcher to vary important quantities, such as shape and material properties, to see effects on vibrational characteristics. G. W. Roberts[4] and O. E. Rogers[5] reproduced the well known nodal behavior of top and back plates using classical Sacconi[6] dimensions, and G. A. Knott[7] and G. W. Roberts[8] developed a model of the entire violin body with the same geometry.

In this paper the top and back plates of an existing violin are modeled using finite element analysis. This particular violin is SUS-264, a violin made by C. M. Hutchins. Holographic studies have been done on these plates by Richardson, Roberts and Walker[9], and a comparison of the finite element analysis with the experimental work will be presented.

THE FINITE ELEMENT METHOD

There exist certain vibration problems that can be solved exactly by means of differential equations. These problems are usually very simple geometrically and structurally. For example, the natural frequencies and mode shapes of thin square steel plate can be completely determined by equations in the literature.[10] Most problems, however, do not have neat solutions, and sophisticated computer analyses must be performed.

Finite element techniques make use of the computer to solve large numbers of equations which simulate the physical properties of the structure being analyzed.[11] This approach can be applied to a wide variety of different structures having a large range of sizes and shapes. Structures as large and diverse in shape as airplanes and ships can be analyzed with much the same approach used for smaller and simpler structures, for example, bolts and welds.

In finite element analysis, the structure of interest is divided into small elements for which solutions can be determined. The violin back and top, for example, were divided into 223 and 258 quadrilateral elements, respectively, as shown in Figure 1. Equations describing the structure of each of these elements are developed within the computer program, and these equations are solved simultaneously by the computer. It is most important to describe the properties of the elements as accurately as possible since the solution can only be as accurate as the input data.

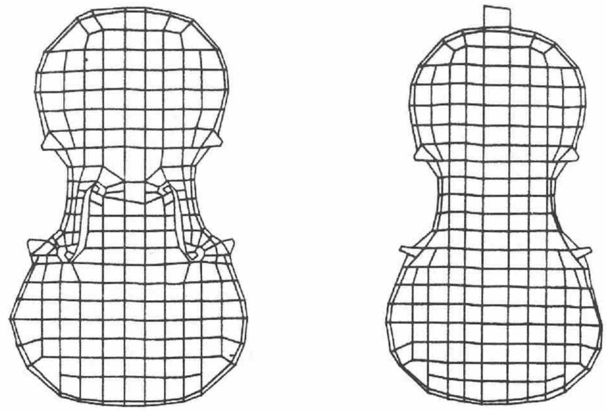

Figure 1. Finite element meshes for the violin top and back plates.

THE VIOLIN MODEL

There are two main considerations in the development of the violin model: (1) geometry and (2) material properties.

(1) Geometry. The violin plates were divided into quadrilateral elements (as shown in Figure 1), and each element was described by eight points: at the four corners, and at the four mid-sides. The x, y, and z coordinates of every one of the corner nodes were measured from the violin. The coordinates of the mid-side nodes were obtained by interpolation from the corner nodes. In addition, the thickness of each element was measured. The elements are treated as thin shells, where different elements may have different thicknesses, but individual elements have constant thickness. This will obviously introduce inaccuracy into the system, although the smaller the element, the less the inaccuracy. The thicknesses used in the modeling were measured from the center of each element. The bass bar was not included.

In addition to characterizing the geometry of the violin back itself, it is necessary to prescribe boundary conditions. Ideally, the back plate would be described as having a completely free boundary, neither clamped nor supported anywhere, and indeed the experimental studies tried to attain this as closely as possible, usually by supporting the violin at places where it was known in advance that there would be minimal vibrations (node points). In the computer model it was necessary to attach the plate somewhere in space so that it didn't move off into infinity, since the first six vibrational modes of a completely free body in space would be rigid body translations in the x, y, and z-directions, and rotations about the x, y, and z-axes. In order to prevent these rigid body motions, models of low frequency springs were attached to the plate models in three arbitrarily chosen places. These served to damp the first six rigid body modes, and it was expected that six extraneous natural frequencies representing these modes would be obtained in addition to the expected plate modes.

(2) Material Properties. Wood is an extremely complex structure which can be described as anisotropic, that is, its material properties are a function of the direction in which they are measured. In addition, the

properties vary with temperature, humidity, and the age of the wood, etc. The back plate of the violin is usually made of maple, and the top plate of spruce. The violin material was assumed, for this study, to be transversely isotropic, that is, it was assumed that there were only two independent directions for the material properties; one in the direction of the wood grain, and the other in a plane perpendicular to the wood grain. This is not quite accurate, since material properties in the perpendicular plane are not uniform, but they are closer in magnitude to each other than they are to the properties in the wood grain direction. The material properties necessary to describe the transversely isotropic material are the wood density, and Young's modulus and the shear modulus in the directions of the wood grain and the plane perpendicular to the wood grain. The values used for the top and back plates are shown in Table 1.

The Young's moduli and densities are average values measured from wood samples for violin plates SUS-264, the actual plates from which the dimensions were taken. The shear moduli were calculated by assuming typical relationships between Young's modulus and the shear modulus based on values in the literature.[12]

Table 1 - Violin Plate Material Properties

	Spruce (Top Plate)	Maple (Back Plate)
E_{Π} [MPa]	15130	12700
$E_{\perp}$ [MPa]	937	1780
G_{Π} [MPa]	930	1270
$G_{\perp}$ [MPa]	59	620
Density [kg/m^3]	430	578

Π Parallel to wood grain
$\perp$ Perpendicular to wood grain

RESULTS

The top row of drawings in Figures 2 and 3 show the first eight eigenmodes for the top and back plates, respectively. These mode shapes indicate where relatively large deflections take place, i.e., the darkened areas indicate relatively large vibrations, whereas the white areas indicate relatively small vibrations. The bottom row of drawings in each figure represents positive vs. negative displacements for the first eight modes, i.e., which part is up and which is down at any given instant. Both rows together should give a clear view of the nature of the vibrations for each mode (i.e., twisting or bending, etc.). The numbers shown indicate the natural frequencies obtained using finite element analysis and, in parentheses, the values obtained by Richardson et al.[9], using holography. Some of these are averaged when several measurements were taken.

In order to see the effect of thickness on the back plate, several runs were made for plates of uniform thickness, t (t = 2mm, 3mm and 4 mm). Table 2 compares the natural frequencies (Hz) of the actual back plate as measured (case 1) to the frequencies for plates of uniform thickness (cases 2, 3, and 4). Figure 4 shows the ring mode (mode 5) for the same 4 cases.

Table 2 - Natural Frequencies for the Back Plate

Mode	Case 1 Actual Thickness	Case 2 t = 2mm	Case 3 t = 3mm	Case 4 t = 4mm
1	121	74	100	124
2	177	115	158	200
3	246	186	250	312
4	307	218	292	363
5	402	320	389	438
6	442	336	440	---
7	523	381	505	---
8	588	451	574	---

DISCUSSION

The finite element mesh used in this work was quite a bit more refined than in previous studies[4,5] (the Sacconi models) which also gave good results. This was done to fit the mesh more closely to the actual dimensions and provide place for fitting the ribs in a future model of the entire violin body. The present mesh is probably more refined than necessary to give good results in the analysis, and thus takes more computer time than a coarser mesh would, but it does provide a very accurate description of the particular violin geometry.

Figures 2 and 3 show excellent agreement between the finite element and experimental studies with the computer analyses consistently giving slightly higher natural frequencies. The mode shapes for the top plate are more symmetric in the computer studies since the bass bar was not included. It would be expected that the bass bar would make the structure stiffer and so raise the natural frequencies of the computer model a little higher.

Table 3 shows the percent error of the computer study compared to the holographics tests. This is instructive because it shows which modes are better characterized than others and indicates how the computer model may be improved.

Table 3 - Percent Error for Finite Element Study As Compared to Holography for Violin SUS-264

Mode	Top Plate	Back Plate
1	13.0	13.1
2	0.6	0.6
3	7.3	6.5
4	6.8	8.1
5	6.3	13.9
6	10.6	6.8
7	10.6	1.9
8	-6.9	18.9

The first few modes appear to be the most revealing for demonstrating modeling problems. Mode 1 gives the poorest results among the early modes, whereas mode 2 shows amazing agreement for both plates. The fact that the errors are consistent for both plates indicates a modeling problem. Mode 1 is a twisting mode; problems with the material stiffness description may be indicated here. The assumption that Young's modulus and the shear modulus are uniform in a plane perpendicular to the wood grain may be causing the calculated stiffnesses to be too high. Another possible cause for error may be the direction of the stiffness properties. The finite element program, ABAQUS, automatically rotates the input material properties into a local coordinate system for each shell element based on the direction of the normal to the element. Whereas this is a sound procedure for most structures, it is inaccurate in the case of violin plates since they are carved rather than bent into shape and thus the wood grain retains its original direction. Thus the material properties have been skewed by the program to the degree that the normal to the surface is not perpendicular to the wood grain.

The effects of various uniform thicknesses on the back plate are what would be expected, with the ring mode being considerably altered and all the frequencies varying in a fairly linear manner.

CONCLUSIONS

It is clear that finite element analysis can give a fairly accurate description of violin plate vibrations. The question that arises at this point is: where to go from here? Below are some thoughts on future developments.

1. A closer look should be taken at the assumption of transverse anisotropy; is it the source of errors for the first mode?

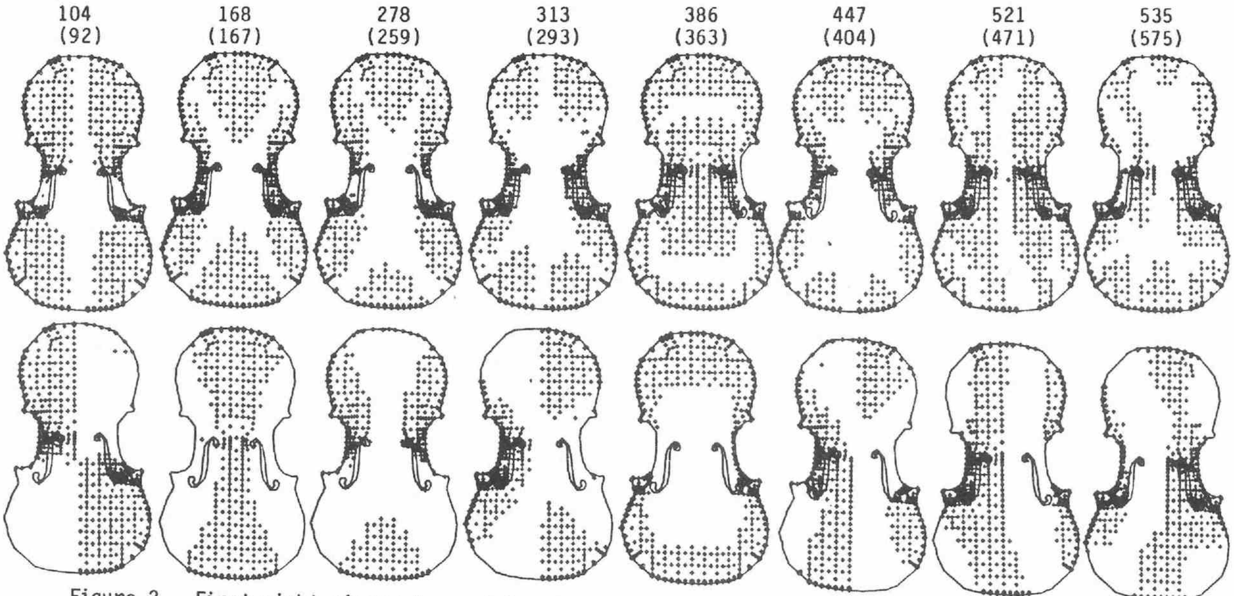

Figure 2. First eight eigenmodes and frequencies of the top plate (numbers in parentheses are average experimental results).

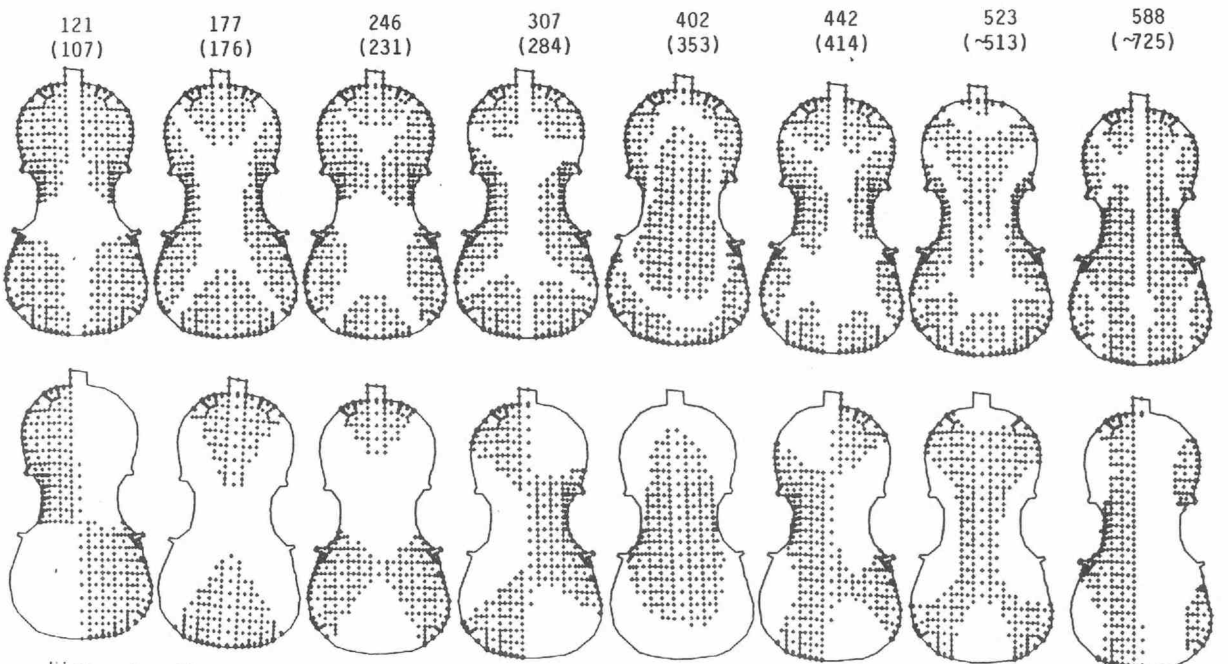

Figure 3. First eight eigenmodes and frequencies of the back plate (numbers in parentheses are average experimental results).

2. The question of orientation of the material axes should be further investigated to see its importance.

3. The bass bar should be added to the model.

4. An attempt should be made to either model the entire violin box by joining the models of the plates to the ribs (and adding the sound post, etc.), or by finding boundary conditions for the plates that will approximate the real boundary conditions. Rogers[4] has done this with success for the back plate.

5. Consider the effects of damping on the wood.

6. Consider the effects of changes in material properties with distance from the midline of the plates.

7. Finally, include modeling of the air cavity and its acoustic properties. This work has been begun with success by Roberts et al.[8]

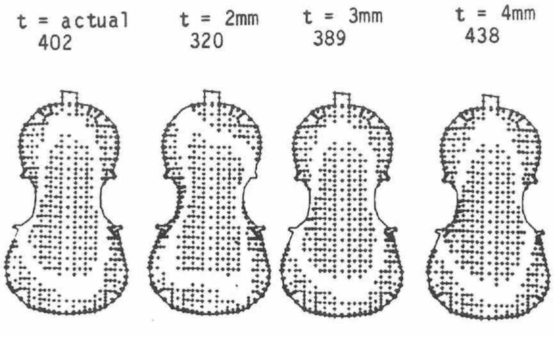

Figure 4. Ring mode for three different uniform thicknesses and actual violin.

ACKNOWLEDGEMENTS

The authors would like to thank Carleen Hutchins for loaning us violins from which to take measurements, and for her essential advice and encouragement throughout this work. We would also like to thank the consulting firm of Hibbitt, Karlsson & Sorensen, Inc. for the use of the finite element code ABAQUS. Both Lisa Kynoch and Qi-Chao Huang deserve much thanks for their help in the tedious job of measuring the violins.

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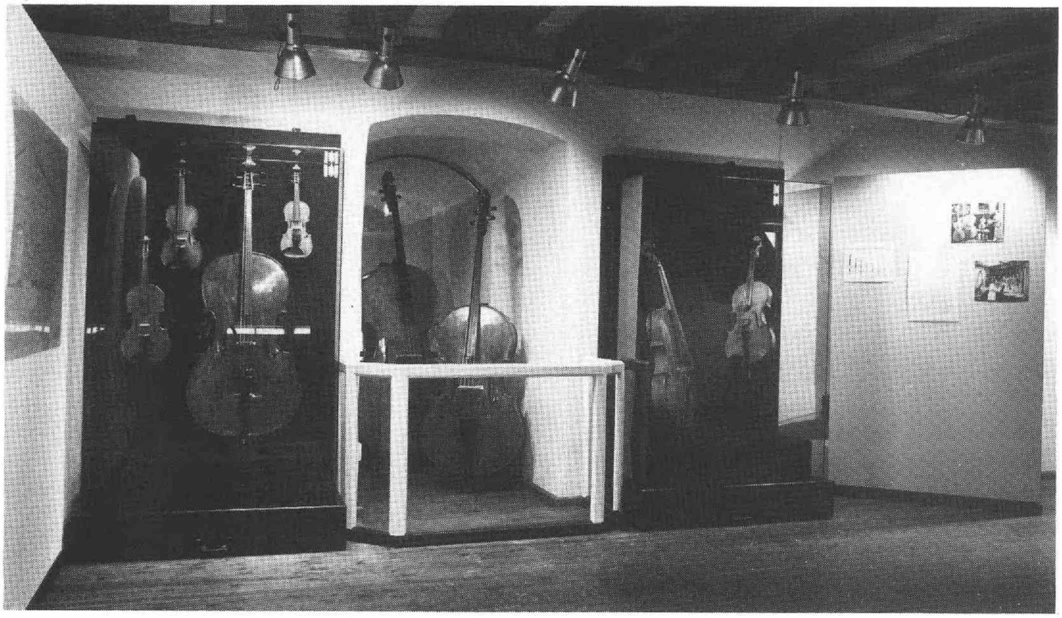

Photo of the exhibition of the VIOLIN OCTET at the SMS-MUSIKMUSEET (Music Museum), Stockholm, Sweden. (March 1985-March 1986). On the right wall - enlarged photos from the CAS OCTET brochure and on the left wall - a full scale working drawing of the Baritone Violin, the large instrument in the nearby case. The exhibit was positioned at the entrance to the exhibition halls and generated as much interest and feed-back as the Museum has ever gotten from a single exhibition.

NUMERICAL MODELLING OF TWO VIOLIN PLATES

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1 Introduction

This is a preliminary communication to describe our attempts to model the modal characteristics of a pair of violin plates (SUS#264), kindly loaned to us by Carleen Hutchins. The modelling consists of finite element calculations to determine the shapes, frequencies and effective masses of the modes, and subsequent analysis to predict the driving-point input admittances. The numerical calculations are compared with practical measurements made on the plates using holographic interferometry and acoustical tests.

2 Finite Element Calculations

We have already used the finite element method to model both free violin plates and the complete bodies of violins (Roberts 1984). These calculations were not based on any one existing violin, but instead the dimensions and material properties were taken from the available literature (Sacconi 1972, Haines 1979). In general, the results compared well with published experimental data for free plates and complete instruments (Hutchins 1971, Jansson 1970, Marshall 1985). However, there could not be any attempt to make detailed, quantitative comparisons with experimental results performed on one particular violin.

The present finite element calculations were performed using NASTRAN running on IBM mainframe computers at the SERC Rutherford Appleton Laboratory near Oxford. Graphical post-processing was performed on a local GEC minicomputer.

To perform the calculations, accurate measurements of the plate geometries and material properties were required. The plate outlines and f-hole shapes were derived photographically, using the plates as opaque masks, and used to generate the finite element meshes. A line negative was then made of each mesh and its projected image was used as a template for measurement points at the nodes of the mesh. We measured the plates' external archings with respect to a flat glass plate, and thicknesses were measured directly. Finally, all dimensions were transferred to the computer.

The arching of the plates was assumed to be bilaterally symmetrical, so arch measurements were made on one half of each plate only. However, thickness measurements varied by a significant amount, so these measurements were made on both halves of the plates.

The meshes of the top and back plates are shown in Figure 1. The plates were modelled using general quadrilateral and triangular shell elements having corner and mid-side nodes. The elements chosen gave a quadratic fit both to the

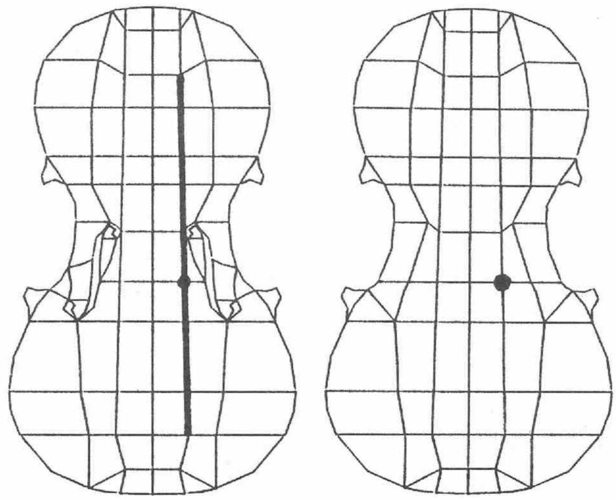

Figure 1. Top and back plate meshes. The thick line on the top plate represents the bass bar and the dots indicate the points at which the input admittances were calculated.

mode shapes and to the actual element geometries (i.e. outline, arching and plate thickness distribution within each element). Although the meshes appear coarse, the quadratic elements actually model the geometry quite well and they are sufficient to obtain reasonable results for frequencies up to about 1 kHz. We acknowledge, however, that the meshes are not fine enough in the vicinity of the plates' edges. There are some rapid changes of slope and thickness in these regions which are likely to affect the shapes and frequencies of modes which involve considerable flexing of the edges. This would be more important in the finished instrument rather than in free plates.

The shell elements allowed orthotropic material properties. Data input required the volume density, two Young moduli, a shear modulus and one Poisson ratio. Hutchins supplied measured values of the density and two Young moduli; these were derived from strip samples cut from waste portions of the plates. The shear modulus and Poisson ratio had not been measured, so typical values were taken from the literature. For the top plate, the bass-bar was modelled using offset isotropic beam elements, because orthotropic beam elements were not available. The data describing the torsional moment of inertia had to be adjusted to mimic orthotropy (see Roberts 1986). No material properties for the bar were available, so these were also estimated. The values used for the material properties are given in Table 1.

Table 1. Material properties used in the finite element calculations.

Material	Density (kg/m^3)	Young moduli (MPa)		Shear modulus (MPa)	Poisson ratio
		E1	E2	G12	v12
Spruce top plate	430	937	15130	850	0.37*
Spruce bass-bar	460	-	15000*	-	0.37*
Maple back plate	578	1780	12700	2000*	0.35*

* Estimated value.

3 Comparison with Experimental Results

The first six modes of vibration of each plate were analysed experimentally using holographic interferometry. We reorientated our holographic system so that the object beam shone down on to the holographic bench. The plates could then be manipulated horizontally and supported on four moveable, medium-hard rubber mounts. These mounts were adjusted so that they lay at vibration nodes. Modes were isolated using Chladni patterns, and then time-averaged interferograms were made of each mode. Note that the relative amplitudes of the interferograms are not indicative of mode strengths.

Figures 2 and 3 show comparisons between the calculated and measured mode shapes and frequencies. The displacement amplitudes of the computed modes have been shown in the form of contour plots, where the contour spacing is equivalent to the spacing of the dark fringes in the interferograms. The overall amplitudes of the computed modes have been adjusted so that there are approximately as many contour lines as dark fringes. The computed mode shapes show reasonable agreement with the interferograms. One exception is Mode 5 in the back plate; this vibration involves considerable flexure at the edges and the inaccuracy is probably due to the coarseness of the mesh in these regions. In general, the predicted frequencies are too high, suggesting that the estimated values of the shear moduli for both plates were too large.

4 Response Calculations

It is instructive to calculate admittance curves for the plates, because these give an indication of the ease with which each mode can be driven from a particular point. The driving point admittance for the plates can be computed if the effective mass at the driving point is known. The effective mass, M, can be obtained using a method described by Schelleng (1963): a small mass is added at the point of interest and the effective mass for each mode is calculated from the shift in mode frequency per added mass, $d\omega_0/dm$, using the formula

$$M = -\tfrac{1}{2}\omega_0/(d\omega_0/dm) \quad .$$

The velocity of a single damped harmonic oscillator of natural frequency ω_0 $(=2\pi f_0)$ driven by a force $F\exp(j\omega t)$ is given by

$$U = \frac{Fe^{j(\omega t-\theta)}}{Z} \quad ,$$

where

$$Z = \frac{M}{\omega}\left[\gamma^2\omega^2+(\omega^2-\omega_0^2)^2\right]^{\frac{1}{2}} \quad ,$$

$$\theta = tan^{-1}\left[\frac{(\omega^2-\omega_0^2)}{\gamma\omega}\right]$$

and $\gamma = \omega_0/Q$, where Q is the Q-value of the resonance.

For a multi-resonant system, the observed velocity amplitude, u, at the driving point is given by

$$u = \left[(\sum\frac{F}{Z_n} cos\theta_n)^2 + (\sum\frac{F}{Z_n} sin\theta_n)^2\right]^{\frac{1}{2}} \quad .$$

The summation ought to be performed over an infinite number of modes, but in practice it is sufficient to include only those modes whose frequencies lie below the upper frequency of interest. The admittance is then simply the ratio of u/F.

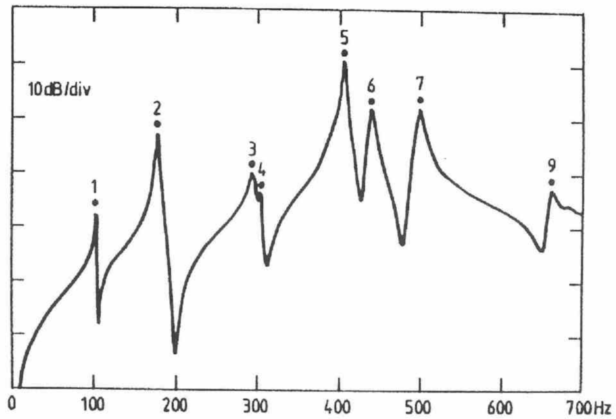

Figure 4. Calculated input admittance of a violin top plate. The numbers highlight resonances of individual modes.

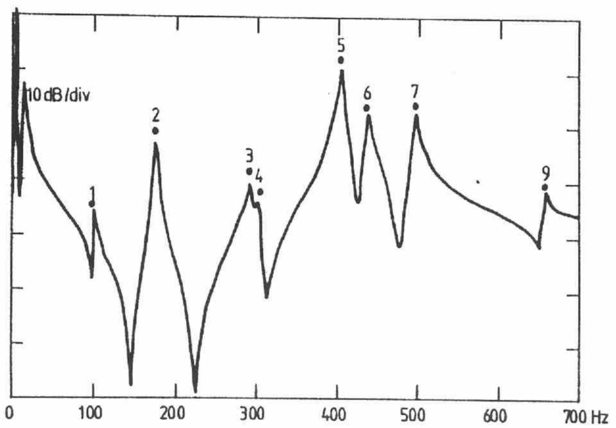

Figure 5. Calculated input admittance of a violin top plate including rigid-body modes.

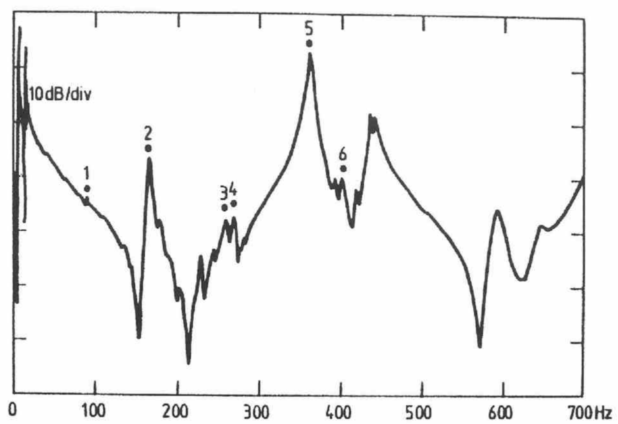

Figure 6. Measured input admittance of a violin top plate (SUS#264).

Table 2. Predicted mode frequencies and effective masses used for the calulation of input admittance. Q-values are taken from experimental measurements.

Mode	Top plate			Back plate		
	Freq/Hz	Mass/kg	Q	Freq/Hz	Mass/kg	Q
1	102.8	>6.000	51	133.6	6.680	56
2	177.5	0.592	46	188.0	>10.000	46
3	295.0	0.819	36	293.3	>15.000	77
4	303.6	1.518	42	358.0	0.617	78
5	404.9	0.082	71	412.9	0.075	65
6	437.9	0.184	60	514.0	0.389	70
7	497.3	0.150	60 *	609.9	0.130	44
8	530.3	8.838	60 *	611.0	>30.000	46
9	658.9	0.824	60 *	698.1	1.745	50 *
10	677.8	4.841	60 *	781.9	2.300	50 *

* Estimated value.

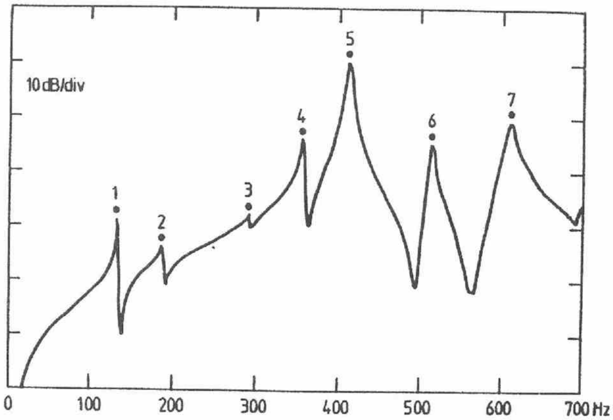

Figure 7. Calculated input admittance of a violin back plate.

Figures 4 and 5 show computed response curves for the top plate, which may be compared with the experimentally-derived response shown in Figure 6. Figure 7 shows a similar computation for the back plate. The first ten modes of each plate were used in the calculations; values of relevant parameters are presented in Table 2. Effective masses were computed at the driving points (Figure 1) using the finite element model to determine the change in mode frequencies which resulted from the addition of a 10 gram point mass added at that point. The finite element results did not include damping, so experimental Q-values, where available, were used instead.

The agreement between the calculated and measured responses was reasonable. The general fit can be improved cosmetically by the addition of two low-frequency resonances (Figure 5) which model rigid-body modes that occurred in the real plate as a result of supporting it on rubber bands. However, neither of the calculated parameters were sufficiently accurate to give a precise fit. This problem arose partly because of the choice of driving position, which was very near to vibration nodes for most of the low-frequency modes. This made experimental determinations of effective masses difficult.

It is encouraging to note that calculated effective masses for the two ring modes (Modes 5) were in good agreement with measured values, because the driving points lay near the antinodes of these modes.

5 Concluding Remarks

We find these preliminary results encouraging. However, more emphasis must be placed on the experimental determination of the relevant material properties and on the calculation of damping characteristics. As noted above, we felt that the finite element mesh was too coarse, particularly in the vicinity of the edges. Future work will include a more refined mesh.

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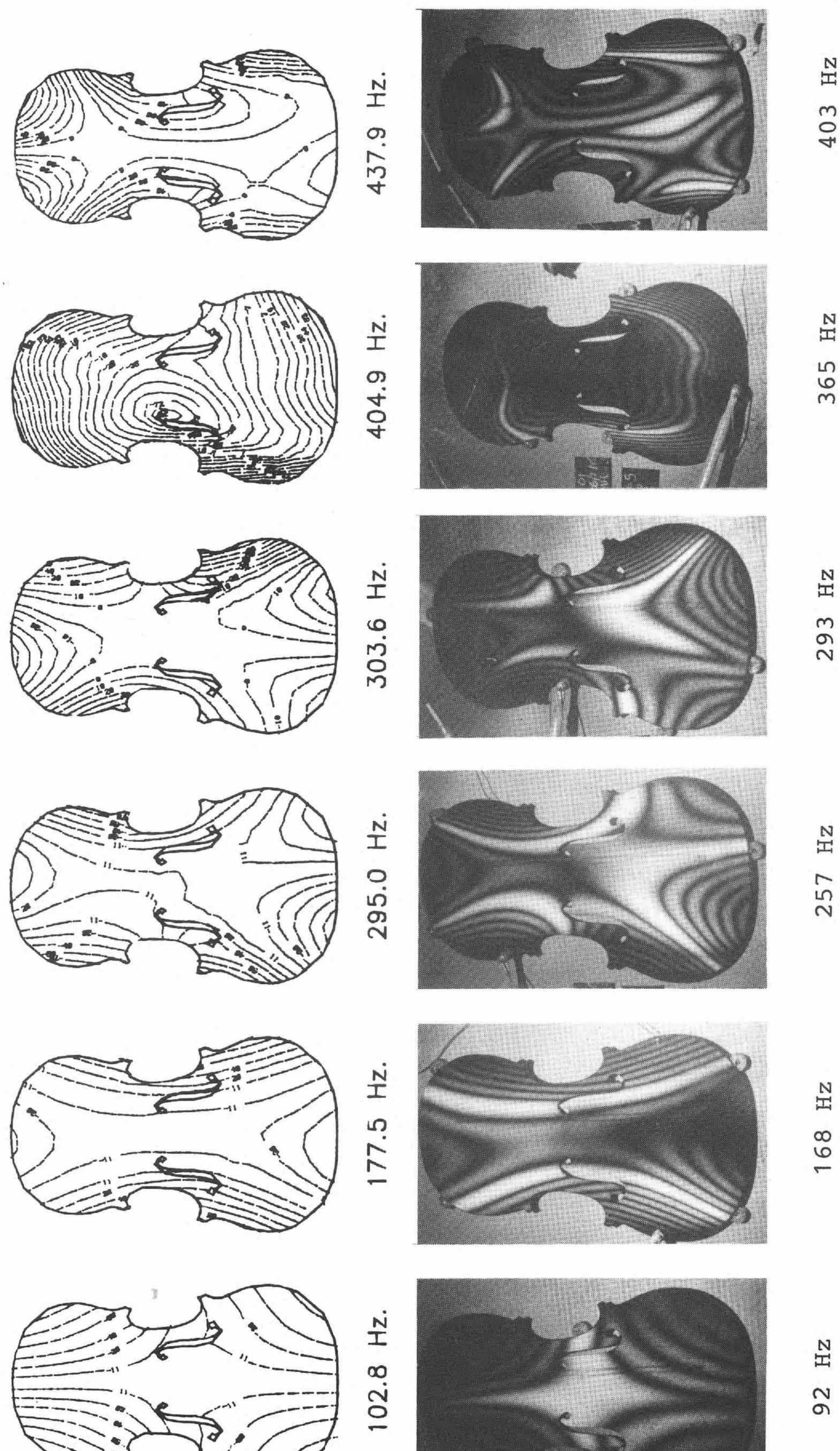

Figure 2. Calculated and observed mode shapes and frequencies of a violin top plate (SUS#264).

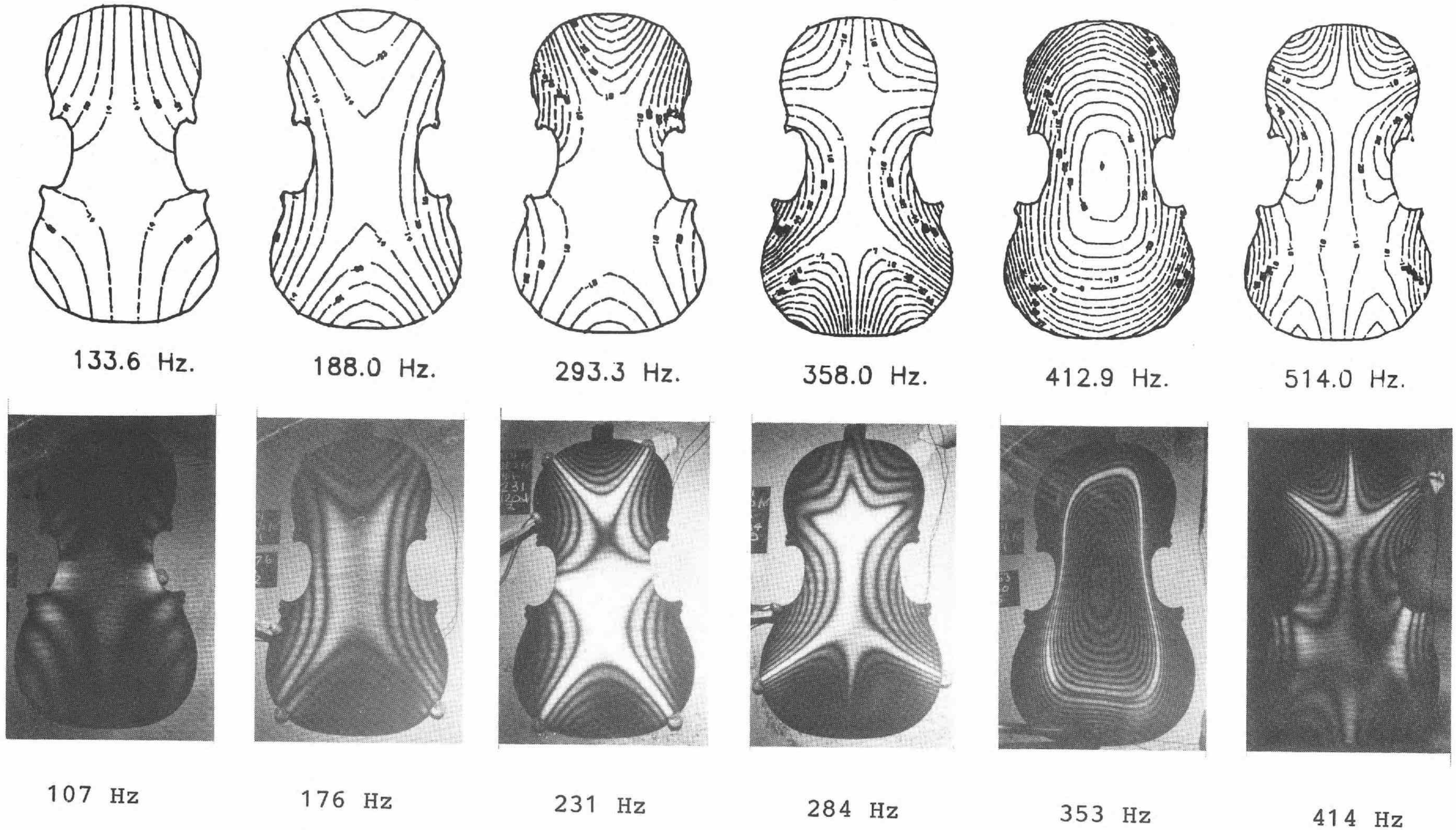

Figure 3. Calculated and observed mode shapes and frequencies of a violin back plate (SUS#264).

CONSTRUCTION AND PERFORMANCE OF QUALITY COMERCIAL VIOLIN STRINGS

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INTRODUCTION

Sets of high quality commercial violin strings have been investigated to discern their construction and their vibrational performance. Strings made by Pirastro in the Olive, Green (Eudoxa), Gold and Black labels have been examined. This report is a continuation of investigations into the design of strings for musical instruments (1,2).

The construction of the strings was obtained from photographs from a Scanning Electron Microscope which, having a calibrated magnification, has the facility of showing on each photograph a marker line of stated length in the object plane under investigation. Dimensions of gut core, nylon underwrap and wrapping wire can thus be obtained from the photgraphs and ckecked by measuring with micrometer. Linear density of strings was obtained by accurately weighing a known length.

The dynamic vibrational behaviour of the violin strings were obtained from measurements on a massive sonometer when the strings were at playing pitch. The frequencies of the harmonics of strings to the ninth or tenth were obtained, and after each measurement of a harmonic the fundamental frequency of the string was checked in case there had been a drift in fundamental pitch during the measurment process, and corrections were made should this have occurred. In this way the inharmonicity of the harmonics of the strings were measured.* Four new G strings from each label were measured.

The lowest string with the largest core diameter was investigated in these studies because inharmonicity should be greatest for violin strings as predicted from the expression for inharmonicity f_n/nf_1 of the nth harmonic f_n (2,3)

$$\frac{f_n}{nf_1} = (1+Bn^2)/(1+B)$$

where

$$B = 8\pi^3 E d_c{}^4/TL^2$$

d_c is the diameter of the core, E Young's modulus of the core material, T the tension in the string, and L the length of the string.

CONSTRUCTION

The constructions of some of the violin strings investigated are shown in Figure 1. These have been selected from the total obtained to show the main features which are present. Strings are made of three parts:

(1) the core is of gut in Pirastro Olive, Green, Gold and Black Label (G,D,A);

(2) there is an intermediate wrapping of nylon or similar very thin mono- filament material which is applied in three different ways - as a floss over-wrapped around the core, as a set of strands overwrapped around the core, or as a braiding knitted around the core;

(3) the outer wrapping of the string is of silver or aluminium, or both together, and the wire which is generally used is circular. In the Olive and Green A the wrap is of rectangular section.

The intermediate winding, or braiding of the gut core is an important part in making overwrapping strings for it enables a better fix to be obtained to the core.

Label	String	OD mm	φ gut + wrap mm	φ core mm	Pitch of gut mm	Circular floss (18μm)	Braiding No. of fibres (18μm)	φ wrap mm	No of wrap	Material of wrap
Pirastro				gut						
Olive	G	.81	.61	.55	6		10/16	.12	3	Ag
Green	G	.81	.63	.56	5		10/16	.12	2	Ag
Gold	G	.82	.64	.61	5.5	10		.12	2	Ag
Black	G	.85	.63	.61	5.1	10		.12	2	Ag
				gut						
Olive	D	.85	.67	.61	6		7 x 12	.11	3	Al, Ag, Al
Gold	D	.87	.63	.63	5	10		.15	2	Al
Black	D	.86	.63	.60	5	10		.14	2	Al
				gut						
Olive	A	.62	.54	.54	6.5		NIL	.07	1 x Rect	Al
Green	A	.66	.56	.49	6.5	10		.07	1 x Rect	Al
Gold	A	.69	.54	.54	6.5		NIL	.09	2 x 0	Al
Black	A	.69	.53	.53	6.5		NIL	.09	2 x 0	Al
				steel						
Flexocor	A	.48		.24(=.07x7)	2.4		7x12 lengthwise	.06	1 Rect	Al
				gut						
Perfection	G	.81	.65	.6				.12	2 x 0	Ag
	D	.86	.65	.6				.15	2 x 0	Ag
	A	.67		.55				.08	2 x 0	Al
Pirastro Wonderton	D	.86	.61	.61				.15	2 x 0	Al June

TABLE 1

The difficulty of making overwrapped gut strings has been noted from the earliest times (4), and to obtain a good adhesion between winding and core, which, because of its low Young's modulus, stretches considerably when tuned to pitch, is an important aspect of manufacture.

Table 1 gives data for the construction of the strings, and Figure 2 shows this data plotted for the strings and gives the tension (T) and the tensile stress ($T_S = 4T/\pi d^2$), for a violin at pitch, with Pirastro wire E added.

SEM photographs of strings (Fig.1) show that braiding for the intermediate wrap is used in Olive and Green Label strings, whereas simple floss overwrapping is used in Gold and Black. The surface finish of the metal wrapping, produced in all cases by longitudinal working, is better polished in the Olive and Green than in the Gold and Black. In Olive and Green polishing has been carried out longer to obtain a nearly smooth surface and there is considerable cold working of the metal wrapping to fill the gaps between adjacent windings. In Gold and Black there are depressions between windings because of incomplete polishing.

INHARMONICITY

Inharmonicity, defined above, has been calculated from measurements on G strings for the Pirastro Olive, Green, Gold and Black Label and the results are shown in Figure 3. Inharmonicity arranged over four strings is plotted in Figure 3 in cents and standard deviation for each harmonic is indicated. Figure 3 indicates that strings are ordered from high to low inharmonicity as Green, Olive, Gold and Black, and the standard deviation of measurments increases in

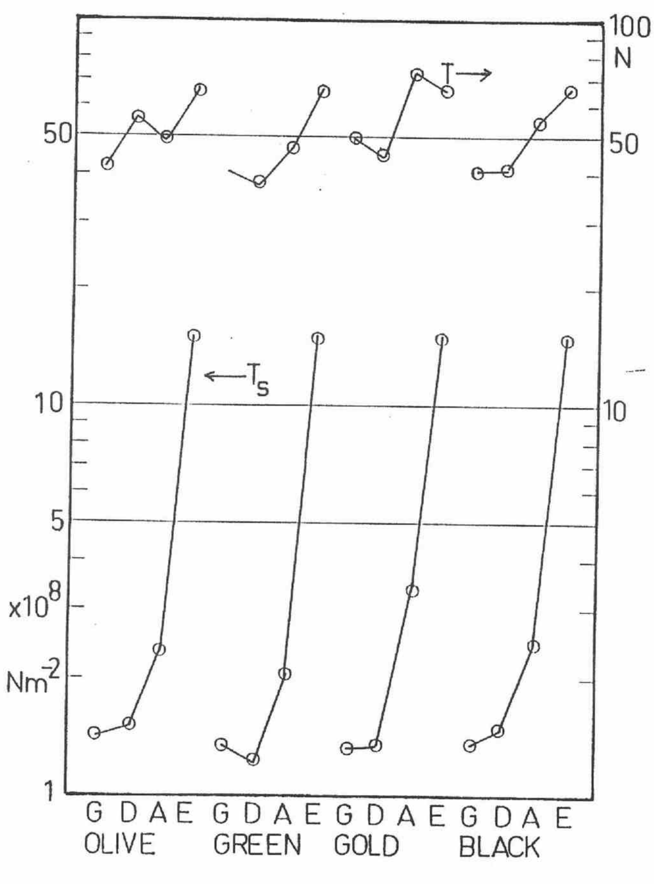

FIGURE 2. Calculated tension and tensile stress for Olive, Green, Gold and Black Pirastro Violin Strings tabulated in Table 1.

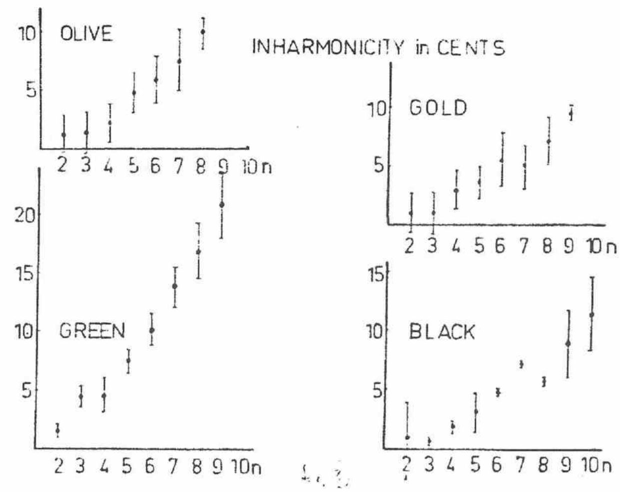

Figure 3. Measured inharmonicity for Olive, Green, Gold and Black Pirastro violin G strings plotted in cents versus the harmonic number, n of the partials of the strings.

the order Olive, Green, Gold and Black. It would appear, therefore, that the simple construction of Black where a nylon floss is used for the intermediate wrapping gives a lower inharmonicity than the more complicated braid knitted around the core in other labels. Nevertheless, the superior finish of the Olive, and Green strings leads to a smaller standard deviation in measurements, which could be ascribed to a better quality control during manufacture. This is reflected also in the price of the strings which are ordered from high to low price as Olive, Green, Gold and Black.

It is apparently the case that there is a preference by players ordered Olive, Green, Gold and Black which is clearly not dictated by market price. This is the reverse order to inharmonicity, but is that of finish both from the final surface of the string for the bow and the complexity of manufacture. Preference must be due to the playablility of the string from the mechanical and practical standpoint: good surface, firm and lasting adhesion of the windings on the gut core. It is clear that a good playing regime among the harmonics can be established in the Olive and Gold, although their inharmonicity is higher than the others, and it would be interesting to establish if the Quality Factors of the harmonics of these strings, which were not measured in this study, are lower than Gold and Black due to the different intermediate wrapping in the string.

ACKNOWLEDGEMENTS

The SEM photography was undertaken at the Scottish Universities SEM Facility at the University of Edinburgh and it is a pleasure to thank Mr Jim Goodall for his pleasant and patient assistance. Measurements of inharmonicity were made by Miss Amanda Gallacher, and calculations leading to Figure 2 were undertaken by Miss Clare Sykes who are both thanked for their meticulous work. The support of Salvi Harps in this project is gratefully acknowledged.

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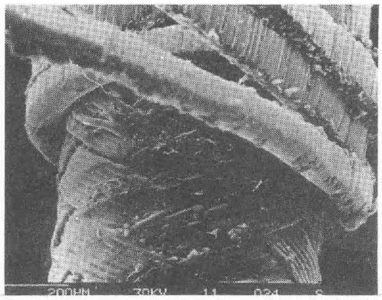
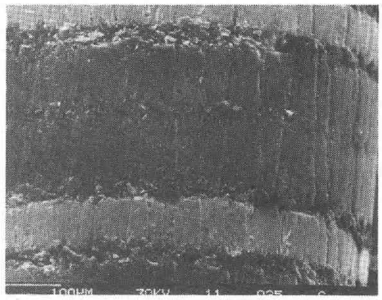
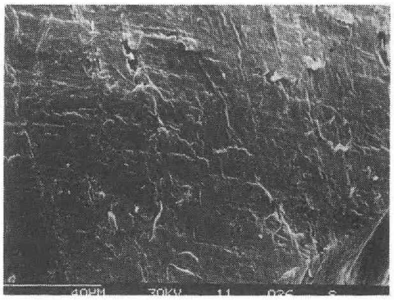


(a) Showing three circular wrappings (Al,Ag,Al) over a brading of 7 x 20 μm nylon. Indentations of the wires are seen in the brading.

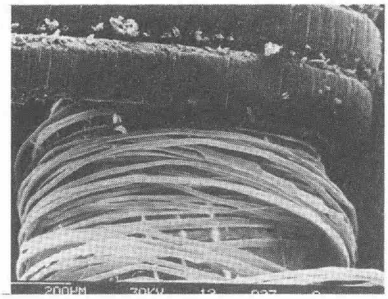


(b) Surface of the overwrap wires, from the top Ag 94μm, Al 105μm, Al 105μm, Ag 94μm. Surface polishing is longitudinal with surface scratches to 5μm, and the indentations between windings nearly filled with cold worked material.

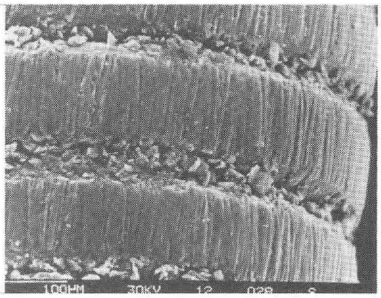


(c) Surface of the gut core of the string which is under the braid in (a). Surface has been profiled by centerless grinding to about 1-2 m. Right hand bottom shows the cut made in exposing the string.

PRIASTRO VIOLIN OLIVE D

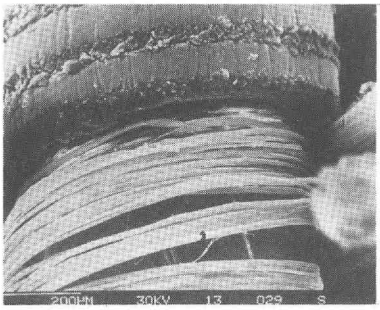


(a) Wire wrap in this string is two strands of Al 140 m wrapped into a nylon floss wound circumferentially around the gut core.

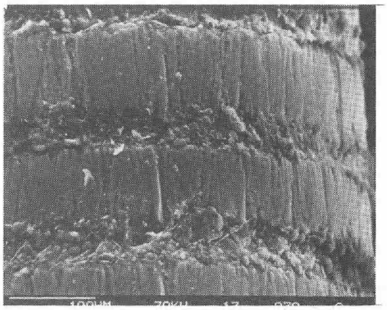


(b) Surface polishing of the Al wrap is longitudinal, but the spaces between the windings are incompletely filled.

PIRASTRO VIOLIN GOLD D



(a) Wrapping is two wires of Al onto a circularly wound floss of nylon over the gut core.



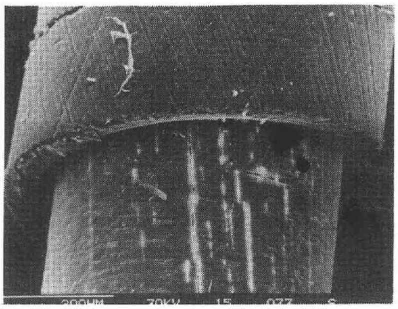
(b) Surface polishing of the Al wrap showing that the spaces between winding are nearly filled.

PIRASTRO VIOLIN BLACK D

* * * * *

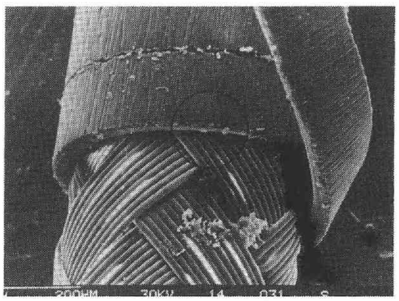
Ian Firth, Professor of Physics at St. Andrews University, Scotland, longtime active member and contributor to our JOURNAL, has engendered great interest in the harp, both its historical and acoustical aspects. His work was recently written up in the St. Andrews "Courier".

PIRASTRO VIOLIN OLIVE A

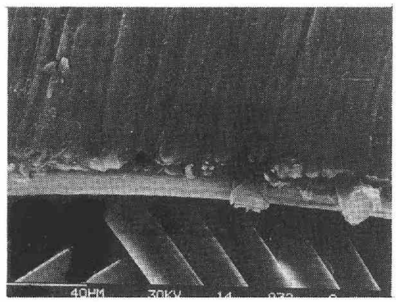


(a) Rectangular Al wire is wound directly onto the gut core. The flat winding is polished longitudinally, here with slight helical marks.

PIRASTRO VIOLIN GREEN A

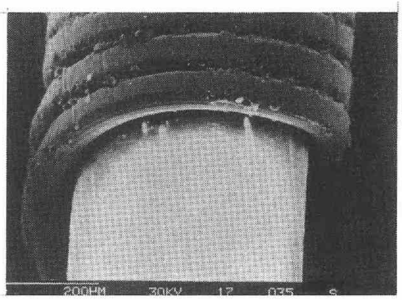


(a) Rectangular Al wire is wrapped onto a smooth brading of nylon overwrapped onto the gut core.



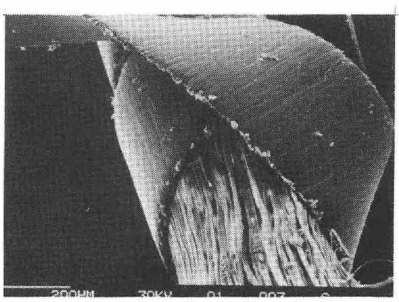
(b) Surface finish of the Al flat wire showing longitudinal polishing to about 5µm, some cold working of the material to fill the spaces between winding, and the undistorted nylon brading undreneath.

PIRASTRO VIOLIN BLACK A

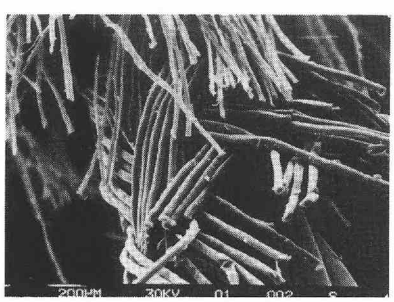


(a) Circular Al wrappings onto gut core with imperfect polishing of the outer surfact so that the spaces between windings are incompletely filled.

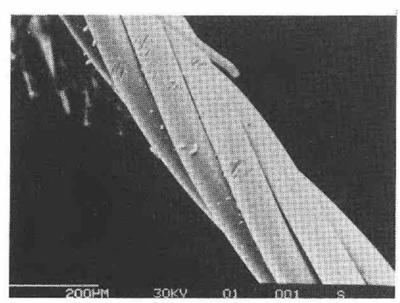
PIRASTRO VIOLIN FLEXOCORE A



(a) General view of the rectangular Al wire wound over a longitudinal nylon floss. Surface of the Al flat winding is along the length of the string.



(b) View of the end cut of the longitudinal floss exposing underneath a brading of nylon woven onto the wire rope core.



(c) Wire rope of steel strands as the core of this string in order to produce a string of great transverse flexibility, and hence small inharmonicity.

ON BORE SHAPE OF A SHAKUHACHI AND ITS RESONANCE CHARACTERISTICS

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1. INTRODUCTION

The shakuhachi is representative of Japanese wind instruments. This instrument is made so that it retains native shape of its material, a bamboo cane. Such a manner of making is taken not only for its outer appearance but also for its bore shape pattern. Therefore, each instrument widely differs in structural dimensions such as tone-hole positions, wall thickness and bore shape (inner diameter curve along with its bore axis). These differences in structure bring about a wide variety of musical character of the shakuhachi, and such variety is an important factor of Japanese music. But, on the other hand, shakuhachi making is very troublesome because of this wide difference.

This study is projected to systematize computer programs with which the appropriate structural dimensions, such as tone hole positions and bore shape pattern can be determined for making a shakuhachi from a certain bamboo material. Such a program system will be useful also for choosing a bamboo material suitable for making a shakuhachi which has a required pitch temperament and a desired timbre character.

In the previous ICA in Paris[1], the author reported the effect of the bore shape pattern observed in contemporary shakuhachis on their pitch temperament. The shakuhachi bore is widened at the upper part and narrowed in the lower part. (An example is shown in Fig. 1.) This bore shape pattern stems from the native shape of a bamboo cane. The inner diameter of the bamboo part used for a shakuhachi is the smallest at the 4th lowest node. The narrowest part of the shakuhachi bore near the lower end corresponds to this 4th node. The widened part just below the mouth end originates in the widest part between the 6th lowest node and the 7th one at which the embouchure is located. But the bore shape pattern is not entirely the native inner pattern of a bamboo cane of which nodes are removed. For example, the sudden widening at the lower end is due to maker's work, though a slight widening exists already in this part of the bamboo cane.

The theme reported in the previous ICA is that how and to what extent the octave interval between the 1st and 2nd mode changes with variation of the widening in the upper joint or narrowing in the lower joint. In tuning of a woodwind instrument, either of the two modes can be tuned easily by means of adjustment of tone hole positions and the whole length. But the interval between the two modes can not be tuned unless the bore shape is varied appropriately.

The result described in the ICA is that the widening has octave stretching effect while narrowing has compressing effect. Based on this finding, the author composed a computer program to correct the pitch temperament of any shaku~~hachi of contemporary type~~. With this program, we can know what amount the positions of toneholes must be shifted and how the bore shape must be changed in order to correct its pitch intonation to a desired temperament. The author applied this program to a shakuhachi made by a present famous maker. The result of this trial was not mentioned in the ICA paper of the author but was added to his oral lecture.

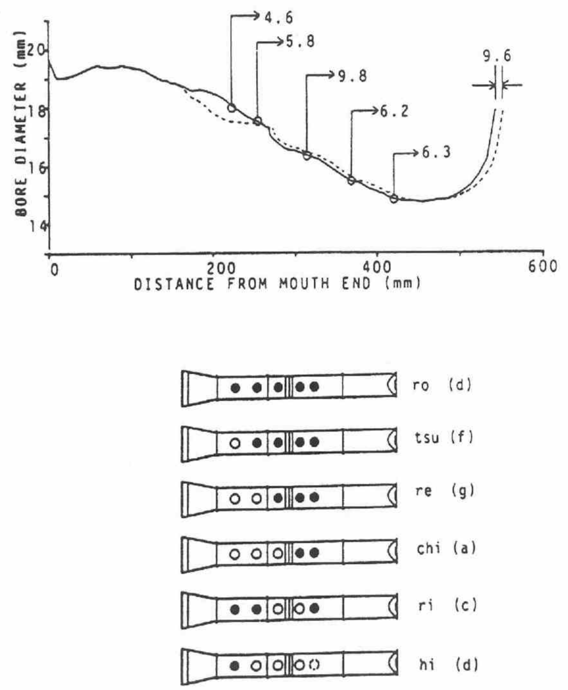

Fig. 1 An applied result of the new method for temperament correction and six elemental fingerings of a shakuhachi

2. ANOTHER WAY OF OCTAVE INTERVAL CHANGE

After ICA in Paris, the author found a more effective way to adjust the octave interval. In this way a short part of the bore is widened or narrowed smoothly. Fig. 1 is an example of its application to a contemporary shakuhachi. The temperament aimed at is 12 equal temperament in concert pitch. The horizontal axis is the distance from the mouth end and vertical axis is the bore diameter. The solid and broken curves represent the original and corrected bore shapes respectively. The arrows and numerals in the figure indicate the shift direction and its amount of the tone hole position and the whole length which are found to be necessary for correcting the pitch temperament. The numerals are in mm unit. In the bottom of Fig. 1, the six elemental fingerings are shown. In the lowest fingering "ro", all tone holes are closed. For a standard sized shakuhachi, nominal pitch of this fingering in the 1st mode is d^1 in German notation. At the highest fingering "hi", the nominal pitch reaches to an octave higher note d^2. The nominal pitches of the other fingerings are as shown in the right part of this figure. Tab. 1 shows the dis -

crepancies of resonance frequencies of 6 elemental fingerings in cent unit before and after the correction. The 1st column is the nominal tone names of the elemental 6 fingerings. The numerals in the 2nd and the 3rd column are the data for the original shape. The 2nd column shows the discrepancy of the 1st resonance frequencies of the lower 5 fingerings ("ro" to "ri") and the 2nd resonance of the top fingering "hi" from 12 equal temperament in concert pitch. The reason why the 2nd resonance is shown for fingering "hi" is that its 1st mode is used scarcely in actual playing. The 3rd column designates the octave stretch between the 1st and the 2nd resonance. The 4th and 5th columns show the halfway data of the correction, where only the values in the 2nd column are tuned by adjustment of tone hole positions and the whole bore length. The 6th and 7th columns show those values obtained after the final correction in which also bore shape is changed for the octave interval turing. We can see the octave intervals are amended well by this way of bore correction. Including fingering "hi", the maximum discrepancy from exact octave is only 7 cents.

Tab. 1 Shakuhachi No. 7 Discrepancy of eather of the two resonances from 12 equal temperament in concert pitch and octave stretch between the two resonances (in cent)

	original shape		only one resonance is tuned		octave interval is corrected	
	one resonance	octave stretch	one resonance	octave stretch	one resonance	octave stretch
ro (d^1)	16.9	10.8	0.1	10.3	0.4	-7.0
tu (f^1)	5.8	27.6	-0.3	26.0	0.0	-5.6
re (g^1)	37.1	32.1	0.1	31.4	0.0	-1.9
chi (a^1)	27.9	15.7	0.3	9.2	0.0	-5.3
ri (c^2)	32.3	-20.7	-0.2	-17.5	-0.3	-4.6
hi (d^2)	32.4	-16.8	0.1	-20.1	-6.8	0.8

* Only for fingering "hi", discrepancy of the 2nd resonance is listed. For the other 5 fingerings, those of the 1st resonances are listed.

3. RESONANCE FREQUENCY AND ADMITTANCE SPECTRUM

The term "resonance frequency" used here means the peak frequency of input admittance which is calculated under the consideration of the end correction at the mouth end in the playing state. As well known, the played pitch frequency of an air-reed instrument such as a western flute or a shakuhachi is markedly lower than its resonance frequency unless the greater part of its mouth hole or mouth end is covered by player's lips. In regard to this phenomenon, Coltman found that the resonance frequency for the flute coincides with played pitch frequency when the resonance is measured under the condition that the mouth opening is covered partly by the player's lips and the bore column is filled with breathed air[2]. The same is said of a shakuhachi[3]. This lowering of the resonance frequency is the effect of the end correction, or in other words the acoustic inertance, which arises at the mouth by sudden narrowing of the cross sectional area of the air column with player's lips. This lowered resonance frequency is the 1st or 2nd peak frequency of the input admittance under the consideration of the end correction. That is, if we connect at the mouth end a short tube whose length is equal to the end correction and measure the input admittance at the open end of this short tube, the peak frequencies of the admittance coincide with the lowered resonance frequencies. In the admittance calculation, which will be mentioned in Section 5, this bore length extension can be easily performed by adding only one reactance calculation.

The coincidence of the peak frequency of the input admittance with the played pitch frequency was described by Yoshikawa and Saneyoshi in their paper on the sound generation mechanism of organ pipes[4]. The author reported the application of their analysis to a shakuhachi in his previous paper[5]. In this paper he also showed that the frequency characteristic of input admittance calculated thus under the existence of the inertance is the determinant factor of harmonic structure of played tones. That is, the level of input admittance at certain multiples of the 1st or 2nd peak frequency determines the level of harmonic in the corresponding order of the 1st or 2nd mode tone respectively. Here, of course, the other conditions such as the driving current or room acoustics are assumed to be constant. From this consideration the author calls the relation among the admittance level at the multiple frequencies "admittance spectrum", and uses this term hereafter. While, to the 1st peak frequency as well as the 2nd one of the input admittance obtained under the consideration of the mouth end correction, the author gives the term "resonance frequency", because they are the resonance frequency itself in the playing state.

Fig. 2 shows some examples of the input admittance curve. The circles in the figure indicate the admittance level at the multiples of the 1st peak frequency. The leftside curves are of shakuhachi bore and right side ones are of cylindrical bore. The upper two are for the lowest fingering "ro" in which all the tone holes are closed. They are the examples of comparatively regular pattern. As for the other fingerings, more irregularity of peak frequency interval and peak height is observed. The bottom curves are of fingering "ri", which are more irregular in lower frequency region. From these curves we can observe that there is close similarity of pattern feature between the shakuhachi bore and the cylindrical one. This indicates that the irregularity of the patterns is owed to the existence of the bore part where tone

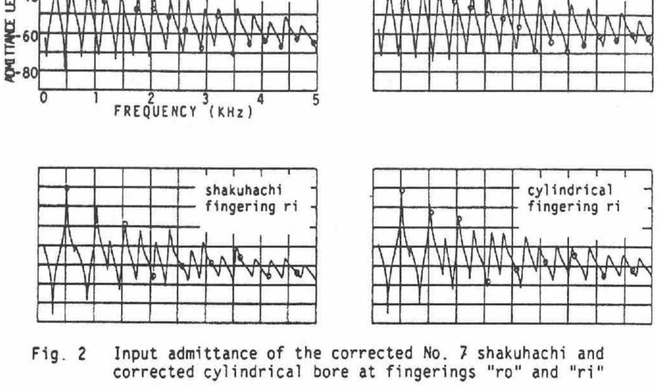

Fig. 2 Input admittance of the corrected No. 7 shakuhachi and corrected cylindrical bore at fingerings "ro" and "ri"

holes are opened. Whether the bore shape is of a shakuhachi or cylindrical has little influence on the gross feature of the admittance curve. But, as mentioned later, close examination of frequency interval between the 1st and 2nd peaks as well as of admittance spectra reveals the difference among these bore shapes.

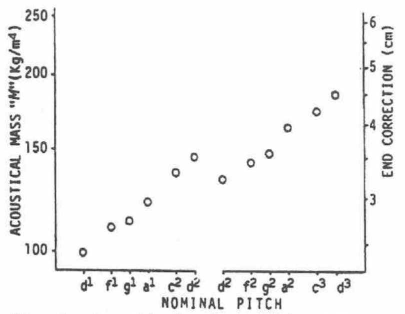

Fig. 3 Acoustic inertance and corresponding end correction length at the mouth end of a shakuhachi in its playing state

The acoustic inertance values used for the calculation of input admittance were determined as follows[5]. At first, the pitch frequencies of played tones were measured. The shakuhachi used in this measurement is that shown in Fig. 1 with a broken curve. The player was Ikuya Kitahara, who is the son of the maker of this shakuhachi and is very skillful in shakuhachi playing. The measured frequencies were converted to those in dry air of 20°C. Secondly, the input admittance was calculated with various magnitudes of the acoustic inertance, and then the relation between the inertance magnitude and the lowest two peak frequencies of the admittance was determined. Finally, from the comparison of this relation with the above mentioned pitch frequencies, the magnitude of acoustic inertance in the playing state was estimated. The obtained inertance value at each fingering in the 1st and 2nd modes is shown in Fig. 3[5]. The left side vertical axis represents the inertance value, and the right side axis the corresponding length of the end correction.

4. COMPARISON OF TEMPERAMENT AND TIMBRE CHARACTERS AMONG 3 BORE SHAPES

The main subject of this report is to find the musical or acoustical meaning of shakuhachi bore shape in connection with pitch temperament and timbre character. For this purpose the octave interval between the 1st and 2nd resonance and admittance spectra of 3 kinds of bore shapes are compared. The bore shapes compared are of a shakuhachi type, cylindrical and conical. The latter two shapes are not perfectly cylindrical or conical, but they are modified for the purpose of getting just tuning in the octave interval as far as possible.

The shakuhachi type bore is the one shown in Fig. 1 by a broken curve. Its original shape shown by a solid curve in the figure is of a typical contemporary shakuhachi made for general professional use by a representative maker, Kozoh Kitahara. The cylindrical and conical bores simulated for comparison are shown in Fig. 4. The broken curves which are seen just below the mouth ends of the cylindrical and conical bores indicate the part modified for the octave interval tuning. These two bores have six tone holes which are equal to those of the shakuhachi in size. Their lengthwise locations are so determined that if we play two assumed instruments which have these bore and embouchures similar to those of the shakuhachi, we can obtain the elemental five tone scale of a standard sized shakuhachi. The reason why the tone hole condition is thus determined is that the resonance characteristic of a bore varies with the intervals between adjacent tone holes.

The diameter of the cylindrical bore before the octave interval correction is equal to the mean value of the shakuhachi's bore diameter. The diameter of the conical bore is determined as follows. The diameter of its mouth end is given the same value to that of the shakuhachi, and then the conicity is chosen so that the total volume of its bore is equal to that of the shakuhachi. Afterwards, the diameters of both ends being kept unchanged, tuning of the 1st resonance frequencies and adjustment of the octave interval were performed. The acoustic inertance value used in this tuning is equal to that used in the above mentioned correction of the shakuhachi temperament.

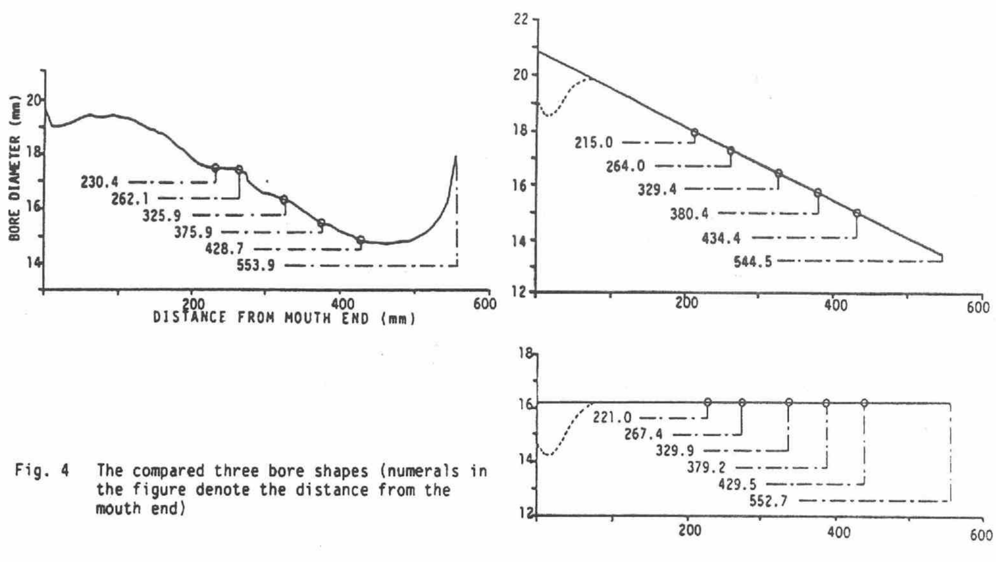

Fig. 4 The compared three bore shapes (numerals in the figure denote the distance from the mouth end)

5. METHOD OF ADMITTANCE CALCULATION

The method of input admittance calculation is almost the same as was reported in the previous ICA paper. A slight improvement was made after Keefe's papers concerning the estimation of tone hole impedance[6,7]. Though the detailed description of the method has been given in another paper of the author[8], it can be outlined as follows. The shape of the shakuhachi bore to be calculated is approximated by a series of short cylindrical tube sections of which inner diameters are equated to the average value of the corresponding part of the bore, and to each tube section the transmission line theory is applied for calculation of input impedance. The calculation starts from input impedance of the farthest tube section which is terminated by radiation impedance of the bore. Then the input impedance of the next farthest tube section is calculated by equating its terminating impedance to the input impedance of the farthest tube section. This process being repeated to the mouth end tube section, the input impedance of the total series of the tubes is obtained. Tone holes are dealt with as T-section circuit inserted at the position of the holes after Keefe's papers[6,7]. The effect of the acoustic inertance at the mouth end can be calculated by adding the reactance of this inertance to the imaginary part of the input impedance.

6. COMPARISON OF OCTAVE INTERVAL

Tab. 2 shows two sorts of discrepancy data for 3 bore shapes. One is difference of the 1st resonance frequencies of the lower 5 fingering "hi" from equal temperament in concert pitch. Another is the octave stretch between the 1st and the 2nd resonance. As mentioned above, the values of the cylindrical and conical bores are not those of perfectly cylindrical or conical but those after the modification for the octave interval correction. Those of the shakuhachi are equal to the values already shown in the 6th and 7th columns of Tab. 1.
We can observe the following features in Tab.2.
(1) As for all three bores, either of the two resonances which is corrected through the adjustment of tone hole positions and the whole length is well tuned. The maximum discrepancy is only 0.6 cent.
(2) For the shakuhachi bore, the maximum discrepancy of the octave interval, namely the maximum absolute value of the octave stretch, is 7.0 cent through the lower 5 fingerings. Those for the cylindrical and conical bores are 11.1 and 6.0 cent respectively.

Tab. 2 Comparison of frequency data of the 3 bore shapes (shakuhachi, cylindrical and conical) after the modification for temperament tuning (Discrepancy of eather of the two resonances* from 12 equal temperament in concert pitch and octave stretch between the two resonances) (in cent)

	shakuhachi		cylindrical		conical	
	one resonance	octave stretch	one resonance	octave stretch	one resonance	octave stretch
ro (d^1)	0.4	-7.0	-0.3	11.4	0.0	4.0
tu (f^1)	0.0	-5.6	0.0	-3.8	0.0	1.5
re (g^1)	0.0	-1.9	0.1	1.3	0.0	6.0
chi (a^1)	0.0	-5.3	0.3	-7.7	0.0	-3.0
ri (c^2)	-0.3	-4.6	0.0	-1.9	-0.3	-1.0
hi (d^2)	0.0	-6.8	0.1	8.2	0.6	-13.8

* Only for fingering "hi", discrepancy of the 2nd resonance is listed. For the other 5 fingerings, those of the 1st resonances are listed.

From these values we can conclude that as far as only the pitch temperament is concerned the shakuhachi and conical bores are slightly better than cylindrical one for use in shakuhachi making.

7. COMPARISON OF ADMITTANCE SPECTRA

Tab. 3 shows the mean values of admittance spectrum levels of each order component through the lower five fingerings. The 1st order component of the spectrum is chosen at the 1st resonance. Therefore the average values in the tables are related to the harmonic levels of the 1st mode tones. The remarkable difference between the shakuhachi bore and the other two bore shapes is observed in the values from the 3rd to the 7th order component levels. The levels of the latter two bore shapes are always lower than that of the shakuhachi one. Owing to this difference, the mean values through levels of the six components of the cylindrical bore are 3dB lower than that of the shakuhachi bore. As for the conical bore, this difference exceeds 5dB. These magnitudes of the difference are regarded to be enough to produce the variation of richness in timbre.

Tab. 3 Mean values of admittance spectrum level through the lower 5 fingerings (in dB*)

order	shakuhachi	cylindrical	conical
2	-13.1	-11.0	-14.8
3	-20.7	-25.8	-24.2
4	-34.8	-37.6	-36.4
5	-34.8	-36.5	-38.6
6	-30.5	-38.3	-39.7
7	-30.5	-33.1	-43.4
average	-27.4	-30.4	-32.9

* relative to the 1st component level

Secondly, the difference in the component level above the 3rd order brings about the dissimilarity of the relative strength of the 2nd order component to that of the 3rd one between the shakuhachi bore and the other two bores. In sounds of woodwinds, the strength of lower even harmonics relative to odd harmonics is very important to their timbre character. It is needless to say that the harmonic structure of a clarinet is characterized by the weakness of its lower even harmonics. Also as for treble recorder tones suitable for baroque music, it was found that the lower even harmonics are desirable to be weaker than odd harmonics. The author reported these findings at the joint meeting of the Acoustical Society of America and the Acoustical Society of Japan held in Hawaii in 1978[9]. Similar preference in harmonic structure was found also for shakuhachi tones suitable for classical shakuhachi music[10].

According to these findings, shakuhachi bore shape is regarded to be more desirable for classical shakuhachi music than conical or cylindrical bore shape. I think this is the most important feature of a shakuhachi bore shape.

8. CONCLUSION

Basing on the above mentioned results, we can describe the musical or acoustical features of the bore shape pattern of a contemporary shakuhachi as follows:

1) As for the octave interval between the 1st and 2nd modes, the shakuhachi bore shape is slightly advantageous, compared to a cylindrical bore. But a conical bore can be tuned by a slight modification of the diameter of its small part.

2) The feature of a shakuhachi bore is observed rather in its timbre character, namely in its structure of admittance spectrum. Firstly, the shakuhachi bore is the most predominant in the weakness of the 2nd component relative to the 3rd one. As mentioned above, the relative weakness is desirable for producing the timbre suitable for classical shakuhachi music.

Secondly, the mean level from the 2nd to the 7th component of the shakuhachi bore is about 3 dB higher than those of the cylindrical and conical bores after the correction.

These differences in the structure of admittance spectra can be regarded as to be enough to bring about dissimilarity of timbre. The differences are deduced on the assumption that the end correction at the mouth end is common to all three bore shapes. If the instruments having the cylindrical or the conical bore described above are blown under the condition that covering rate of their mouth end openings is reduced appropriately, these differences are able to be diminished. Whether such a manner of playing is possible or not is a future problem to be investigated.

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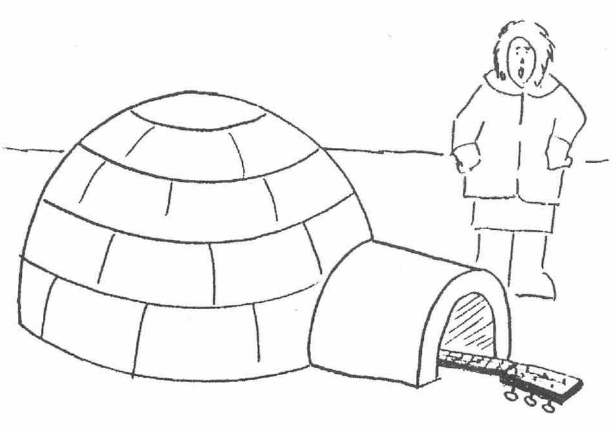
APPENDIX

The accuracy of this method of calculation was examined as follows. At first, the author constructed an apparatus for admittance measurements for the purpose of obtaining reliable data to be used for estimation of the calculation method. With this apparatus, not only the sound pressure but also the particle velocity was measured directly with a hot wire anemometer. This method had been originally applied for input impedance of brass instrument by Pratt and others[11]. The reason why the author chose this method rather than the usual impedance tube method is that it is advantageous for getting accurate data in the neighborhood of peak frequencies where sound pressure is small. Though the maximum error to be expected in this measuring method is 5.3 cent in peak frequencies and 2.2dB in peak levels, the discrepancies observed in triplicate measurements were only 2.2 cent and 1.4dB.

Then a straight cylindrical pipe was made on which 5 side holes like tone holes of a shakuhachi were drilled, its calculated admittance data were compared to its measured ones. The average differences were less than 3 cents in peak frequency and 3dB in its level respectively.

As for levels of higher peaks relative to the 1st peak, as well as the levels at the multiples of the two lowest peak frequencies, the calculated values showed good coincidence with those measured. The discrepancies were less than 2dB.



ASSESSMENT OF INNOVATIONS IN THE CONSTRUCTION OF THE CLASSICAL GUITAR: PART I. ANALYSIS OF TOP-PLATE RESONANCES USING FFT TECHNIQUES AND HOLOGRAPHIC INTERFEROMETRY

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SUMMARY

Detailed measurements as well as subjective assessments have shown that the quality of a guitar is largely determined by the amplitude distributions and quality factors of the main top-plate resonances. Measurements of the acoustic frequency response using impulse excitation and FFT techniques combined with observations using holographic interferometry can provide the constructor with valuable information on these characteristics, opening the way to improved designs.

1. INTRODUCTION

The present form of the acoustic guitar was developed about 150 years ago and since then has undergone little change. Even the well known guitar makers have introduced only minor modifications to the traditional design and, as a result, the performance of the instrument has only shown slow improvement. It is only recently that studies involving detailed measurements of the acoustic frequency response as well as subjective assessments have yielded a great deal of information about the objective criteria which determine the quality of an instrument [1]. In particular, the amplitude distributions and quality factors (Q) of the first four top-plate resonances, which usually lie in the frequency range from 180 to 700 Hz, have been identified as being especially important [2]. At low frequencies these resonances are modified by coupling between the top plate, the back and the enclosed air, with the fundamental in particular being strongly affected by coupling with the air inside the guitar [3,4,5]. In this paper the term "top-plate resonances" describes those observed with this coupling taking place and should not be confused with the unperturbed resonances of the top plate (no coupling). It is of great value to the designer to have a set of techniques which can give accurate information on these parameters from measurements on the complete instrument.

A convenient technique for determining the frequency response of stringed musical instruments is by applying a mechanical impulse to the body of the instrument and performing a fast Fourier transform (FFT) on the acoustic time response [6,7]. Such measurements provide information on the frequencies of the important vibrational modes and their quality factors. We have been able to perform such measurements on a number of guitars and obtain high-quality spectra over a frequency range extending up to 1600 Hz with a relatively simple and inexpensive experimental arrangement.

In addition we have used holographic interferometry to identify the top-plate resonances in the frequency range from 0 to 1600 Hz and study the amplitude distribution in these modes [8,9,10]. We have used these results in conjunction with measurements of the frequency response to obtain an overall picture of the behaviour of this instrument and to assess the effects of departures from traditional construction on its performance.

2. EXPERIMENTAL PROCEDURE

Figure 1 is a block diagram of the experimental arrangement used for measurements of the acoustic frequency response. The impulse was applied to the guitar by an Advance vibrator type 6, which consists basically of a voice coil in a magnet, to which a short, 3 mm diameter brass rod (mass 5.4 g) was attached. The vibrator was excited with a single pulse obtained by triggering an I.E.C F53A function generator. A square pulse with a duration of 7 ms and an amplitude of 30 volts was found to give an adequate acoustic output without any risk of damage to the instrument by the brass striker rod. Because of the small mass of the striker relative to that of the soundboard, it can be assumed that the collision between the striker and the bridge of the guitar is elastic, the impulse duration being determined principally by the elastic characteristics of the striker and the rosewood bridge. The actual duration of the impact was measured by bonding two strips of aluminium foil to the bridge of the guitar. These strips formed part of an electrical circuit which was completed when the brass striker rod closed the gap between the two strips. The duration of the impact was found to be typically about 0.5 ms. If it is assumed that the force on the guitar varies sinusoidally over a half cycle in this interval it would correspond to a 3 dB drop in the excitation at a frequency of approximately 1600 Hz [11].

The acoustic signal from the guitar was picked up by an electret microphone placed directly in front of the bridge at a distance of 0.5 m from the soundboard. This microphone had a frequency response flat to within 1 dB over the range from 50 Hz to 10 kHz. The signal from the microphone was taken to a Nicolet 3091 digital oscilloscope with 12-bit resolution which sampled the signal at 4000 points and stored the sampled values. The stored data were then transferred to a Sirius microcomputer which was used to carry out a FFT on this data. For a sampling interval of 100 μs

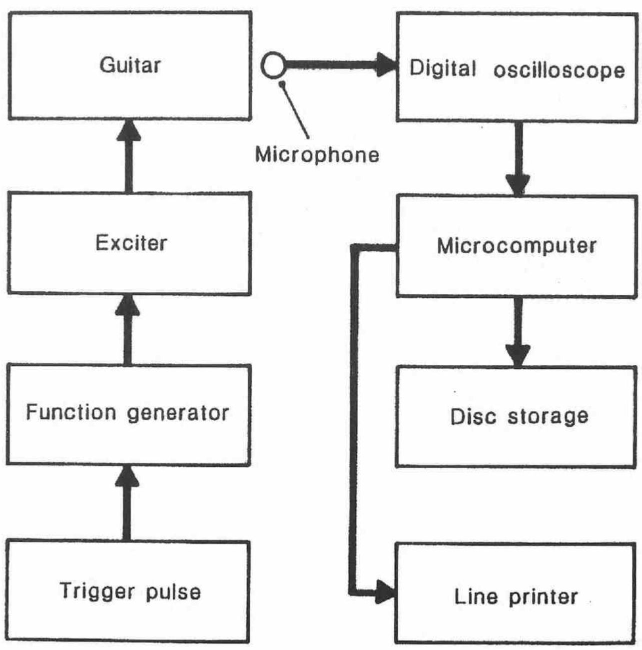

Figure 1. Block diagram of the experimental arrangement used for measurements of the acoustic frequency response of a guitar.

corresponding to a total sampling time of 0.4 second, a frequency resolution of 2.5 Hz was obtained.

Ideally, the acoustical output of the guitar should be integrated over a spherical surface around the guitar which, in practice, requires an array of microphones. The term "frequency response" is thus used rather loosely and the amplitude distribution shown in Figure 3 would be different if either the position of the striker or the microphone were changed. However, the frequencies of the resonances would be unaffected.

The holographic system used in these tests is shown in Figure 2. The guitar was illuminated with the green line (λ = 514 nm) from an argon-ion laser, fitted with an etalon to ensure operation in a single longitudinal mode, and holograms were recorded on a photothermoplastic using a Newport HC 300 holographic camera.

To keep the exposure time to a minimum and to maximize the contrast of the fringes, it was found advantageous to use a matt white coating on the face of the guitar. This coating must not damage the surface finish and must be easy to remove. Calcium carbonate mixed with water and a small amount of PVA glue was found to give good results. This mixture was sprayed on to give an even coating.

Experiments were also carried out to optimize the method of supporting the guitar. The best results were finally obtained with the guitar resting vertically on a metal stand with plasticine wedged around the edges between the guitar and the stand to prevent movement. The guitar was excited by a B & K type MM 002 magnetic transducer coupled to a small mu-metal disc attached to the soundboard with double-sided adhesive tape. Discs were attached at several points on the soundboard and the guitar was driven at the point which best excited the particular mode under study.

The procedure followed was to record a hologram with no excitation applied to the guitar and then to observe on the TV monitor the real-time fringes formed when the transducer was energized [12]. It was then possible, by tuning the oscillator, to locate the resonant frequencies. After optimizing the settings to excite a particular mode, a time-averaged hologram of that mode was recorded [13]. The time-averaged fringes were then photographed, either directly or off the TV monitor.

Some measurements were also made with stroboscopic illumination [14]. Stroboscopic holographic interferometry has the advantage that high contrast real-time fringes are obtained; in addition, it is possible to identify areas displaced in the same sense and those displaced in the opposite sense. An electro-optic modulator was used to modulate the intensity of the beam. This electro-optic modulator was driven by a stroboscopic pulse generator which was synchronized to the oscillator used to excite the guitar and allowed convenient control of the duty cycle of the stroboscopic pulse and its phase with respect to the excitation waveform [15].

3. RESULTS

The results of some measurements carried out on a high quality acoustic guitar (a Ramirez guitar) are presented below. Figure 3 shows a frequency response curve for this guitar, measured as described earlier, when it was excited at the first string position on the bridge. The vertical axis is the sound pressure level normalized to the peak sound pressure level. As can be seen, this guitar radiates strongly at a number of frequencies in the range from 100 to 550 Hz.

For this measurement, the guitar was strung and was held in a horizontal position with its side

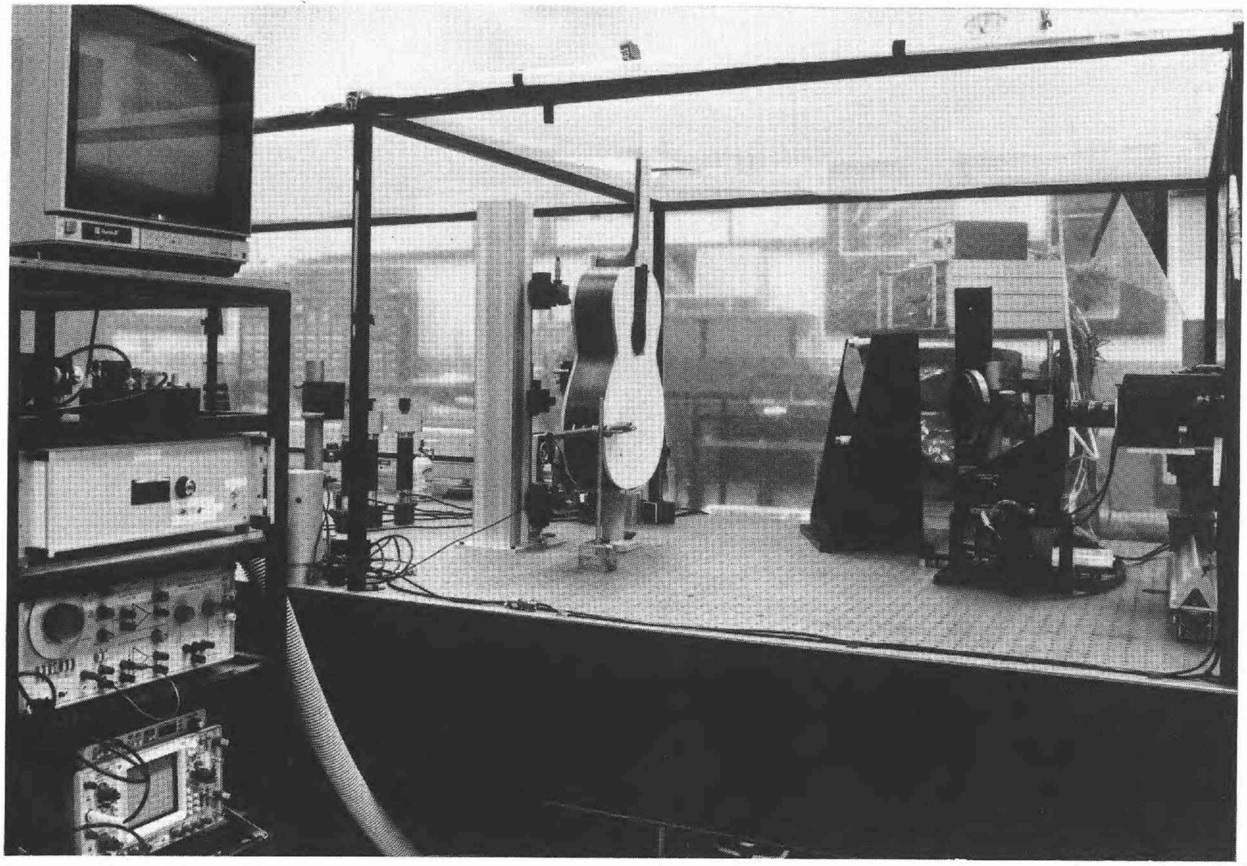

Figure 2. View of the system used for holographic studies of the resonances.

resting on the table and the neck supported with foam rubber. Both the loading of the top plate with string tension and the manner in which the guitar is supported alter the boundary conditions for some modes. As might be expected, the frequency of the fundamental resonance is most affected by changes in the way the guitar is held during testing. The fundamental resonance with the guitar vertical was about 5 Hz lower than when it was in a horizontal position. Since the holographic measurements were most easily carried out with the guitar vertical and without strings, measurements of the resonant frequencies were also made under these conditions. Table I shows the frequencies of twelve of the resonances obtained from the holographic measurements compared with those obtained using the FFT technique under the same conditions. The discrepancy between our values for the resonant frequencies and those obtained by Christensen [16] for a Ramirez guitar may be accounted for by the fact that the top plate of the guitar we tested was constructed from cedar rather than spruce.

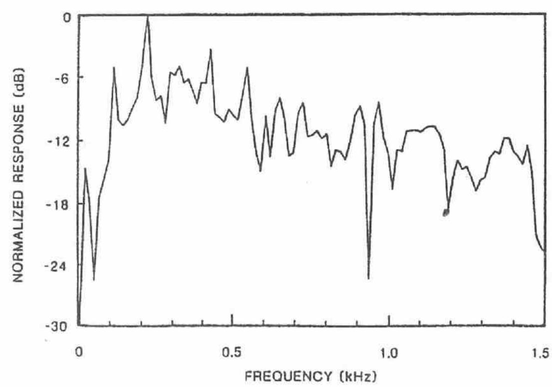

Figure 3. Frequency response of a high-quality acoustic guitar (a Ramirez guitar) excited at the first string position on the bridge.

Some of the time-averaged holograms obtained with this guitar are presented in Figs. 4(a) to 4(f), which show six modes of the guitar corresponding to resonant frequencies of 195, 292, 385, 537, 709 and 905 Hz, respectively. Because of strong coupling with the second air resonance, the third mode splits into a doublet [17] and a pattern similar to that observed at 385 Hz is obtained at a frequency of 420 Hz, though with the nodal line shifted slightly further towards the soundhole. As a result of the difference in the position of the nodal line, the acoustic output for excitation at the bridge for the resonance at 385 Hz is less than it is for the resonance at 420 Hz and to obtain the hologram shown in Figure 4(c) the guitar was excited below the bridge. The curve shown in Figure 3 indicates a difference in sound pressure level of 6dB between the peaks for the two resonances. While the resonance at 385 Hz is not "major" it is included for interest in Table I. Although this behaviour was observed with the Ramirez it did not occur with other guitars tested. If the uncoupled resonant frequencies of the air and the top plate are very close together then an undetectable shift will occur since the "split" modes overlap. This is believed to have been the case for the guitars tested other than the Ramirez.

Frequencies of major top-plate resonances (Hz)

FFT	Holography
103	103
207	195
285	292
388	385
420	420
535	537
647	647
666	666
710	709
723	724
798	800
902	905

TABLE I

The holograms support the view that good performance is linked to a degree of asymmetry in the bracing. A high degree of symmetry can produce high-frequency modes which radiate inefficiently and are difficult to excite, since the bridge lies in a nodal region. As can be seen from Fig. 4(a), the antinode of the fundamental top-plate mode is displaced laterally to the wing of the bridge. This has little or no effect on the acoustic output from this mode. However, radiation from the other modes in the mid- to low-frequency range is increased. This feature is probably responsible for the 'warm', typically Spanish sound of this guitar. In particular, for good subjective quality, the third mode should be strongly radiative and have a high quality factor [1]. To obtain strong radiation, one part of the soundboard should radiate from a greater area and undergo a greater excursion from the equilibrium position than the other. This guitar obviously meets this requirement.

Measurements were also carried out using these techniques on a set of prototype guitars with soundboard bracing arrangements which differed considerably from those found in traditional instruments. The results of these studies will be presented in Part II of this paper.

4. CONCLUSIONS

We have made measurements of the acoustic frequency response of guitars using impulse excitation and FFT techniques. We have also used holographic interferometry to identify the important top-plate resonances and evaluate the amplitude distribution of these resonances. Such observations provide the constructor with valuable quantitative information on guitar performance and open the way to improved designs.

ACKNOWLEDGEMENTS

The authors thank Prof. T. Rossing for his many useful suggestions and comments. We also thank C.M. Chidley for his skilled assistance with these measurements.

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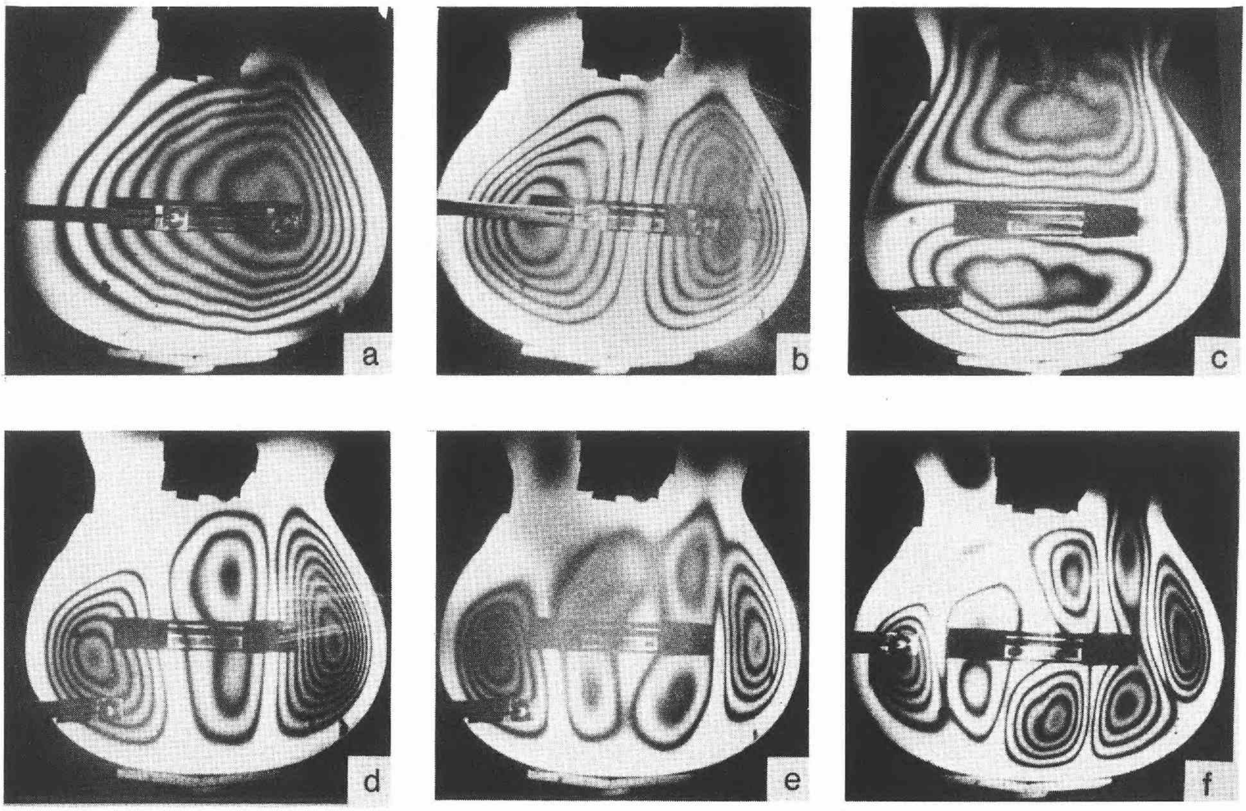

Figure 4. Time-averaged holograms showing the resonances corresponding to frequencies of (a) 195, (b) 292, (c) 385, (d) 537, (e) 709 and (f) 905 Hz.

ASSESSMENT OF INNOVATIONS IN THE CONSTRUCTION OF THE CLASSICAL GUITAR: PART II. NEW DEVELOPMENTS IN GUITAR CONSTRUCTION

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SUMMARY

Prototype guitars have been constructed incorporating some new features. These include modified radial bracing patterns, the use of a composite of carbon fibre and balsa as the soundboard bracing material and a bridge that is thicker at the edge than in the centre. These modifications have led to improved acoustic output and performance at high frequencies.

1. INTRODUCTION

Towards the end of the eighteenth century a major advance was made in the construction of the classical guitar. The bracing of the top plate (the soundboard) which until then had run across the grain, was glued along the grain by some makers. This had the effect of increasing the strength of the guitar in the direction of the string tension and also resulted in improved acoustic performance. In the mid-nineteenth century, this basic idea was refined by Antonio Torres [1], who also increased the size of the guitar to approach that of modern instruments. Almost all makers since then have used soundboard bracing arrangements which are based on that of Torres.

Most guitar makers selectively thin some areas of the soundboard, usually around the periphery, to enhance the lower-order top-plate resonances. Earlier studies have also shown the influence of stiffness along the grain and across the grain on the frequencies of the top-plate resonances [2]. In addition, the frequency distribution of the radiated acoustical energy has been studied and the properties of the first four top-plate resonances, which are important for good performance of the guitar, as determined by subjective assessment, have been identified [4,5]. There is some disagreement over the importance of the back and sides to the acoustical performance of the instrument. However, the resonances of the top plate and the enclosed air and the coupling between them have by far the most influence on the sound. Since the air resonances are set by the geometry, which is fixed, the structure of the top plate is the dominant factor determining the guitar's performance. In spite of this, little work has been reported in the literature on this aspect of guitar design and the internal bracing of the soundboard has remained basically unchanged for the last hundred years.

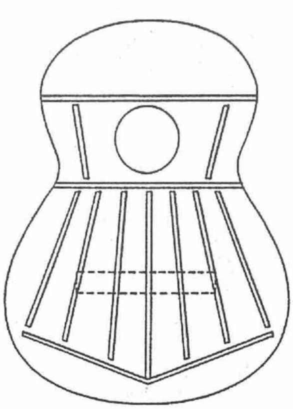

Figure 1. Soundboard bracing pattern used by Antonio Torres.

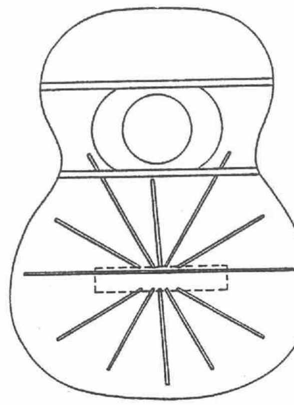

Figure 2. New radial soundboard bracing pattern.

2. NEW DESIGNS

2.1 Radial Soundboard Bracing

The basic bracing pattern used by Torres [1] is shown in Figure 1. This design continues to be the most widely used, with small modifications by individual constructors.

A new radial soundboard bracing arrangement developed by one of the authors (S. M.) is shown in Figure 2. In this design the bracing has been broken into two halves which radiate from a point under the bridge of the guitar. In addition to the fan braces, a large brace runs across the grain under the bridge. The rationale behind this approach stems from the fact that cross-grain stiffness is an important factor in determining the resonant frequencies of many top-plate modes [2,3]. The new design allows the stiffness of a greater area of the soundboard to be controlled than with the traditional Torres design. In addition, the stress from the tension of the strings is distributed more evenly over the area of the soundboard. By moving the point from which the braces radiate towards the side of the guitar, the centre of mass of the soundboard can be moved. This allows some flexibility in controlling the frequency of the fundamental resonance and its Q factor.

The basic design shown in Fig. 2 appears to have considerable potential for improving guitar performance. Several prototypes have been constructed using this concept but differing with respect to the number, distribution and symmetry of the braces.

Western red cedar was used in all these trials as the material for the soundboard.

2.2 Carbon Fibre and Balsa Braces

Spruce is commonly used for the bracing. The characteristics of the braces are extremely important in achieving structural stability and good acoustical performance. We have therefore studied the use of a composite of carbon fibre and balsa for the soundboard braces. This material has a higher stiffness-to-weight ratio compared to wood and reduced damping at high frequencies. Compared to West German spruce an improvement of approximately 30% is obtained in the stiffness-to-weight ratio and the logarithmic decrement is reduced from 0.021 at 1 kHz for spruce to 0.014 for the composite [6]. The effects of using carbon fibre-balsa braces were determined by constructing guitars identical in every respect except that one was braced with the composite material and the other with spruce. As an additional precaution, timber from adjacent cuts from the same billet was used for the soundboards.

2.3 Bridge Design

The mass and shape of the bridge have significant effects on the resonant frequencies and shapes of the top-plate resonances [2,5]. In addition, it is important to consider the function of the bridge as a soundboard brace, since its stiffness is an important factor in determining the tonal balance of the instrument. Improved structural and acoustic performance was obtained in these experiments by using a bridge with the profile shown in Figure 3(a) instead of that more commonly employed, which is shown in Figure 3(b). With the new profile, the bridge is stiffest at the edges, and there is a visible reduction in the deformation of the bridge. The acoustic effect is to raise the frequencies of some of the top-plate resonances by increasing the cross-grain stiffness [2].

Figure 3. Guitar bridge profiles: (a) the new design (b) conventional design.

3. EXPERIMENTS TO EVALUATE THE NEW DESIGNS

Subjective tests were performed in which music from different eras was played before groups of listeners, some who were familiar with guitar music and others who were not. Only two guitars were compared in each test and individual reactions to the instruments were noted.

For subjective assessments of the effects of changes in the design of the bridge, recordings were made of one of the prototype guitars with one or the other bridge in place. These were then played back through headphones.

For the objective loudness comparisons a Larson Davis 800B sound pressure level meter with a filter to match the response of the ear was used at a distance of one metre from the guitar under test to measure its output. The meter can be used either to take instantaneous measurements of sound pressure level or to make cumulative measurements, i.e., the response of the meter is incremented at each new measurement of sound pressure level. For our tests the meter was used in the latter mode. Tests were performed in which chromatic scales were played across the six strings, the sound pressure level meter adding the output from each played note (measured in dB) to obtain a total. The average sound pressure produced by an individual note could then be calculated.

4. RESULTS

4.1 Soundboard Bracing

Some of the results obtained with two of the prototype guitars, A and B, using the radial soundboard bracing pattern shown in Figure 2 are presented below. The bracing for guitar B was the same as that for guitar A except that the material used was a carbon fibre-balsa composite instead of spruce.

Subjective tests showed that guitar A gave a distinct impression of improved clarity and brightness when compared with a high-quality guitar of conventional construction (the Ramirez guitar discussed in Part I of this paper). However, guitar B, which was braced with the composite, was louder overall and was rated better in subjective tests than the spruce braced guitar (A). Figure 4 is a frequency response curve for guitar B. A comparison of this curve with that for the Ramirez guitar (see Figure 3 in Part I of this paper) [7] shows increased output at frequencies up to 1000 Hz. The objective tests indicated that, on average, the sound pressure level of a note played on guitar B was 4 db higher than for the Ramirez and 1 db higher than for guitar A.

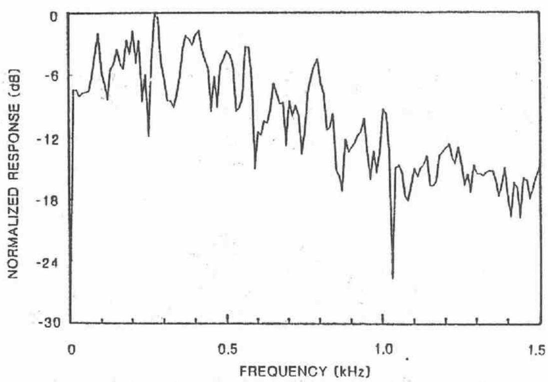

Figure 4. Frequency response of guitar B.

Further tests using holographic interferometry showed that the patterns obtained at soundboard resonances for guitars A and B were very similar, indicating that the use of carbon fibre in the soundboard braces did not significantly affect the general form of the modes. However, while the first three modes for these guitars occured at approximately the same frequencies and had the same shapes as on conventional guitars, the higher-order modes were very different. Some of the time-averaged holograms obtained with guitar B are presented in Figures 5(a) to 5(i), which show the modes at resonant frequencies of 400, 480, 540, 645, 760, 840, 920 and 1100 Hz respectively. In

particular, figure 5(b) which shows the fourth mode on guitar B should be compared with Figure 4(d) in Part I of this paper, which shows the fourth mode of a conventional guitar. For guitar B, the mode which is normally the fourth has become the sixth and occurs at a frequency of 645 Hz instead of the more typical frequency of about 540 Hz. Figures 5(e), 5(f), 5(g) and 5(h) show radially symmetric patterns corresponding to new modes which replace the normal modes in the frequency range up to 1000 Hz. These modes are a consequence of the radial form of the bracing used on the soundboard. The presence of a larger number of modes improves the performance of the guitar in this frequency range, since there are more resonances over the same frequency interval.

The holograms of the higher-order modes of guitars A and B with frequencies above 800 Hz suggested that for the high-frequency modes exhibiting radial symmetry, energy was not being transferred as efficiently as desired to the soundboard from the bridge, since it lay in a nodal region, and that a further improvement in performance could be obtained by introducing some degree of asymmetry in the bracing pattern.

Tests were therefore carried out with another prototype (guitar C). Carbon fibre-balsa composite material was used in this prototype also for the braces. However, the bracing pattern was made slightly asymmetric by making the braces radiate from a point located approximately 15 mm from the center line of the guitar on the bass side of the soundboard and altering slightly the orientation of the braces with respect to the grain from the pattern shown in Figure 2. In addition, the shape of the transverse brace immediately below the soundhole was modified by reducing its stiffness near the edges of the soundboard, to improve radiation from the third mode.

Figure 6 shows the frequency response of this guitar (C), while Figure 7 shows two of its higher-order modes. The introduction of asymmetry in the bracing pattern has several important effects. In the first instance, it raises the frequency of the fundamental resonance by moving the center of mass of the soundboard towards the edge of the guitar and lowers the Q of this resonance. This also has the effect, through coupling with the air volume, of raising the frequency of the coupled "air" resonance. In guitars A and B, this resonance occurs at a frequency of 93 Hz, which is undesirably close to a note (F sharp), whereas in guitar C it is at 97 Hz. Finally, the introduction of asymmetry improves the coupling of the bridge to the higher-order modes (which would otherwise exhibit radial symmetry) by skewing the vibrating areas. As a result, these modes can be excited more easily by the vibrations of the bridge.

The resultant improvement in the response at high frequencies was shown up quite strongly in subjective tests. It can also be seen from a comparison of Figure 6 with Figure 4 as well as the response curve for the Ramirez guitar (Figure 3 in part I of this paper).

4.2 Bridge Design

The listening tests, carried out on guitar A, in which comparisons were made with a conventional bridge and the new design, showed that the use of the new bridge resulted in a significant improvement in the treble. The general consensus was that, with the new bridge, the guitar sounded brighter and clearer. This suggests that the effect of the new bridge is to alter the energy distribution with more energy being radiated by higher order modes than with a conventional bridge.

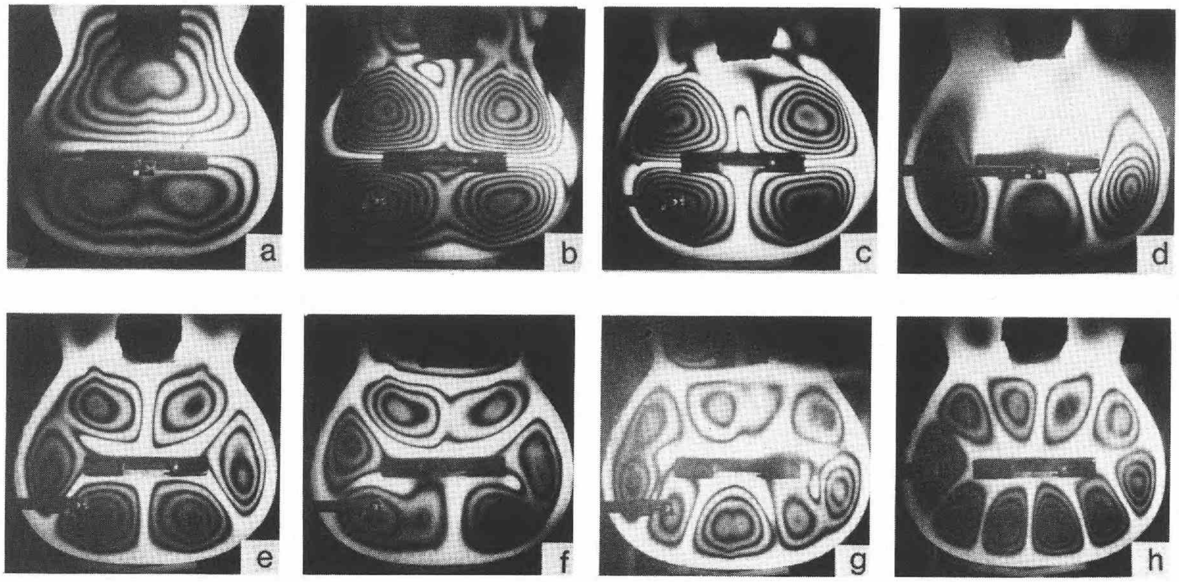

Figure 5. Time-averaged holograms showing the resonances of guitar B corresponding to frequencies of (a) 400, (b) 480, (c) 540, (d) 645, (e) 760, (f) 840, (g) 920 and (i) 1100 Hz.

5. DISCUSSION

Since a strongly radiative third top-plate resonance is of particular importance in gaining a favourable subjective impression [5], any bracing pattern used should allow this mode to radiate efficiently. The frequency response curve should indicate both a high relative output and a high Q for this mode. This criterion is satisfied by all three prototype guitars.

The distribution of energy between the resonances occurring in the mid-range between about 400 Hz and 800 Hz is very important to the way a guitar is assessed subjectively [4]. It is an open question whether a 'warm' sound (high in low frequency energy) is preferable to a 'bright' sound (high in high frequency energy). However, since high frequencies are attenuated more rapidly than low frequencies in an auditorium, a concert guitar should radiate strongly at high frequencies. With the new bracing pattern, some modes are shifted to higher frequencies and new modes are observed. Guitars with the new bracing pattern therefore radiate strongly in the mid-range, as well as at higher frequencies above 800 Hz. This results in instruments which are well suited to contrapuntal styles of music, as individual 'voices' in the music are easily distinguished.

The present study also confirms the important contribution of the bridge to good acoustic performance. Modifications to the profile of the bridge can raise the resonant frequencies of many of the modes, resulting in improved treble response.

6. CONCLUSIONS

Prototype guitars have been constructed which incorporate a new bracing pattern and a carbon fibre-balsa composite as the soundboard bracing material, as well as novel features in the design of the bridge. These changes have led to improvements in the acoustic output and the performance at high frequencies.

ACKNOWLEDGEMENTS

The authors thank Prof. T. Rossing for his many useful suggestions and comments. We also thank C.M. Chidley for his skilled assistance with these measurements.

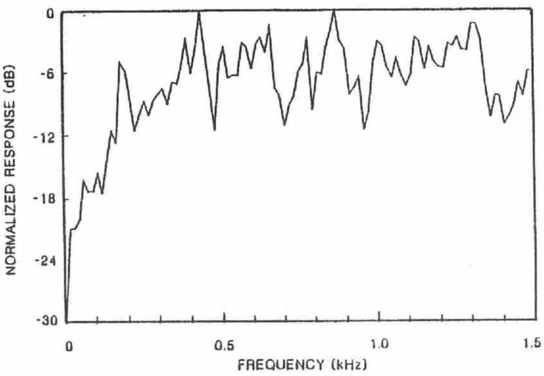

Figure 6. Frequency response of guitar C.

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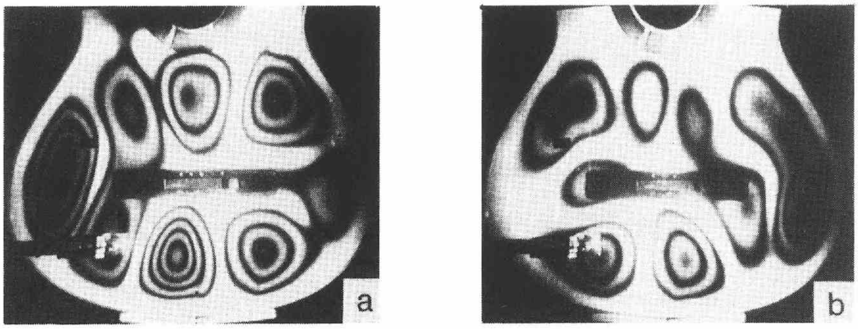

Figure 7. Time-averaged holograms showing the higher-order resonances of guitar C at frequencies of (a) 952, and (b) 996 Hz.

A MUSICIAN'S SPECTRUM ANALYZER FOR VIOLINS

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1. Introduction

The problem of objective evaluation of violin tone quality is a formidable one which has occupied many serious investigators for a long time. There is a strong body of opinion which believes, quite sincerely, that efforts in this direction are useless because violin tone quality is not subject to measurement or "scientific" study; rather, it is an ineffable property of these remarkable instruments which can only be judged by human ears. It is a corollary of this conviction that no particular training or experience is essential in sorting out good from bad instruments - and preferences are usually expressed firmly.

Unfortunately, such judgements are subject to change with time and test conditions. Instruments favored today may drop from favor tomorrow. Often, new instruments are accused of rapid tonal deterioration, and there is no proof that they do or do not decline. Furthermore, if a violin carries a famous name or a large price tag, favorable tonal ratings are almost inevitable, even if the instrument is deficient in power, as so many are. Results of repairs are difficult to appraise, especially if considerable time has passed while they were in progress, and optimization of soundpost and bridge adjustment is always debatable.

For all these reasons, it is useful to have a reliable and repeatable method of documenting the acoustic performance of a given violin at a particular time. It is not to be expected that any system of measurement will ever substitute for evaluation by a skilled performer. The player is influenced by the "feel" and appearance of the instrument, and quite properly so, but factual information on the intensity and spectral distribution of the sound can be compared with that from violins of known high quality, even if there is no such instrument available at the moment. There is no practical way to make "absolute" measurements of a violin's acoustical performance; one must contend with the awkward fact that what is heard by a microphone depends alarmingly on its position relative to the instrument being played and to the dimensions and boundary conditions of the surrounding space. The equipment and method to be described were developed to give repeatable results from which meaningful comparisons can be made between instruments, or different conditions within the same one judged for effectiveness. The resulting permanent record serves as useful documentation.

2. History

Many investigators have devised methods of making and recording violin spectra. The work described here began in about 1970 with excitation provided by a lateral disc recording cutter applied to the string notches in the bridge. The instrument under test was held at the chinrest position by a soft clamp, and the neck rested in a padded crotch. This assembly was mounted horizontally a few inches above a large rigid reflecting panel, with a single cardioid microphone, ten inches above the bridge, collecting the sound. The oscillator driving the cutterhead derived from a spectrum analyzer; the microphone signal was applied through a tracking filter in the analyzer to a chart recorder. About 100 instruments were subjected to this treatment, but unequivocal distinction between "good" and "bad" violins was not evident from comparison of the complex graphs.

Acquisition of a digital computer in the late seventies suggested its use to analyze these spectra by other than visual means. Data recording was done through slow analog to digital converters, and many computer programs were written to try to unlock the secret of good violin tone quality. It was soon found that better methods of driving the bridge were needed, since anything in continuous contact altered the acoustic output. The successful answer to this was found in the development of a precise impact hammer which struck the edge of the bridge in the direction of normal bowing. 1024 impulses were required for a single test; a narrow-band filter was advanced in logarithmic steps, after each tap, over the range from 100 to 8000 Hz. Various holding schemes were tried, the most reliable being vertical suspension on rubber bands. Results were saved on a digital plotter and on magnetic tape. (Figs. 1-4).

The advent of fast analog to digital converters and relatively powerful desktop computers made it possible to use Fourier analysis to derive a frequency spectrum from a single tap. (Fig.5) It was now possible to generate even more data in a given time period. Certain features common to professional quality violins were emerging, but rating instruments by spectral analysis seemed as elusive as ever, especially when it was found necessary to use microphones in several positions to obtain enough significant data. (Front, back and side radiation can differ enough to effect radically different perceptions between player and listeners in a given situation.) After approximately 300 sets of measurements made in this way, it was realized that simplification was needed.

In the early nineteen eighties, advances in integrated circuits brought forth digitally-programmable switched-capacitor filters. These were used to construct a 94-channel logarithmically spaced filter, controlled by the computer. With three microphones, this reduced the number of data points from over 3000 to fewer than 300. Computer programs for analysis were much simpler and faster, and there was no apparent penalty in the reduced resolution at high frequencies. At low frequencies, the resolution was about the same as it was in the FFT spectra. Two methods of excitation are being used with this system: repeated taps on the bridge, as before (94 instead of 1024), and bowing by machine. The latter requires a brief description: The violin is held horizontally in a fixture which incorporates a roller mechanism which rides on the fingerboard to establish the string length. A standard violin bow, driven by a reciprocating mechanism, produces the sound. Adjustments for bow pressure, velocity and distance from the bridge are provided. Each string is bowed in turn, while the effective string length is slowly changed over a range of one and one-half octaves. A single microphone is used, and the computer saves the highest output from each of the 94 filters. The method is slow and tedious, but does give useful information about balance between strings and the effect of principal resonances when excited by different strings. (Fig.6 and Fig.7)

3. The Subject Method.

Although the bridge-tapping method gives information of value in diagnosis of instrument faults and virtues, it is not practical for everyday use on short notice, nor is it a

convincing method in the eyes (or ears) of non-technical musicians. The sound of bridge tapping is too suggestive of instrument damage (although there never has been any at all) and extrapolation of such unnatural tone production to musical results is too wide a step for most violinists to accept. It became necessary to develop a method which could be used with no special preparation, and which takes data from the sound made as the violin is bowed by a human player.

The player stands in a marked location in a large room. Three identical microphones are in fixed positions approximately 15 inches to the right, below and above the center of the violin as it is played. The player is instructed to play a slow chromatic scale, one note at a time, from the open G to the first D on the E string. The duration of each note is adjusted to a blinking metronome light. Intonation and uniformity of intensity are both monitored; inputs out of limits are rejected. A seven-octave spectrum of each note in one-third octave bands is transmitted to the host computer, together with the true RMS level of each tone, unfiltered. The maximum variation in level is also transmitted; useful in identifying wolfnotes and/or uneven bowing.

Three runs are made, one for each microphone. The total time required is less than ten minutes. Repeatability has proven to be of the order of 1 to 2 decibels with the same player in the same position in the same room. Because they may habitually play at different distances from the bridge, different players show variations in average level and minor differences in high-frequency output. These are small compared to the differences in spectral distribution from one instrument to another. Because of the necessity of maintaining accurate intonation and controlled bow velocity, only proficient players can successfully complete test runs with this equipment. This was, of course, intentional.

4. Instrumentation

The analyzer which controls data taking is the result of a development program which began in 1982. It is controlled by a dedicated microprocessor, the program for which is contained in read-only memory. Microphone inputs are switched successively to a preamplifier which applies the signal to 21 one-third-octave filters in parallel and to one true RMS converter, which produces a DC output rigorously proportional to the root-mean-square value of the audio

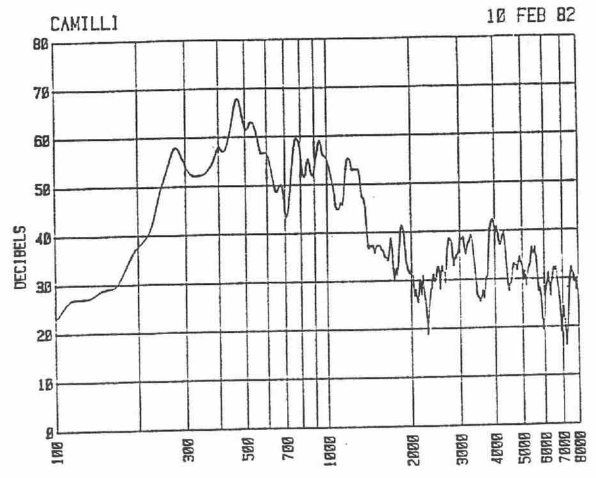

Fig.1. Violin by Camillus Camilli, 1735. Fine old Italian instrument.

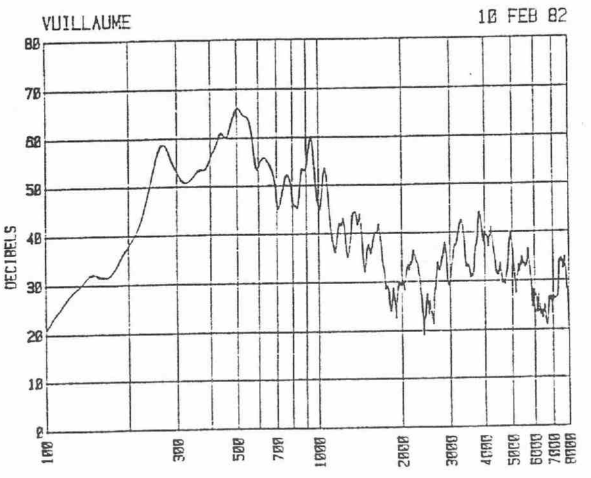

Fig.2. J.B.Vuillaume, 1863. Another excellent concert-quality violin.

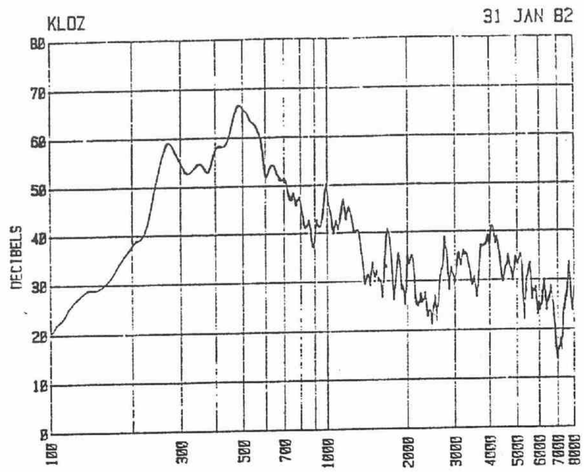

Fig.3. Aegidius Kloz, 1795. Dark tone, lacking brilliance and power. Note region around 1000 Hz. compared to others.

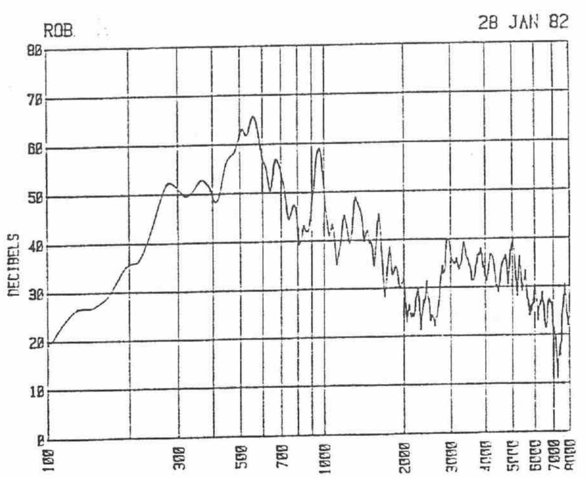

Fig.4. Violin by student maker. Thin tone. Note weak low frequencies.

Spectra made by repeated bridge taps with a moving narrow-band filter.

signal. Filter frequencies are centered on 110, 220, 440 etc. Hz. for the seven octaves, and the two additional values to complete each octave. The entire set is flat within plus or minus 0.5 dB. from 100 to 12,000 Hz. The lowest octave is of little use for violins, but was included to cope with violas.

The 22 separate outputs are fed through analog switches to a 10-bit analog to digital converter. A flashing light controlled by the microprocessor serves as a metronome; the player has previously been instructed in its use. Programmed bow velocity is about 25 centimeters per second. During the 2.1 seconds duration of each note, the filters are scanned eight times after an initial delay of 400 milliseconds, and the results averaged. If the RMS value for a given note varies by more than 2 dB., the player is instructed to repeat it; if it does not improve after three tries it is accepted, but flagged as a possible "wolf". If a note is not sustained for at least 2.1 seconds, it is also rejected. The initial delay screens out unwanted transients.

The timing for the entire operation is derived from a 10 Mhz. crystal oscillator. This also serves to control period measurements for each note played. A separate bandpass filter with a Q of 25 is switched successively to the frequencies of the tempered scale based on A 440. The period of each note is compared with a table in computer memory; any difference greater than 10 cents will cause a panel light to indicate the direction of the discrepancy, sharp or flat, and will interrupt data transfer. This feature was added after observing how greatly the amplitude of a note near a sharp peak can be affected by small lapses in intonation.

A series of indicators on the panel tell the player what note to play, and whether his effort has been successful. Good players have no trouble maintaining the steadiness and intonation required. Proper tuning of the instrument is assisted by a commercial tuning indicator mounted on the panel. For each note played, the data is transmitted to the host computer by a serial interface operating at 1200 baud. The average of eight scans for each filter and the RMS converter, the level variation for each filter and the converter, and the actual period of the note played are transmitted for each of the 32 notes. Each transmission consists of 45 16-bit binary numbers which are converted to decimal as they are received by the host computer. The analyzer microcomputer is interrupted during the transmission, and is released by a handshake from the host when transmission is complete. This takes about 100 milliseconds.

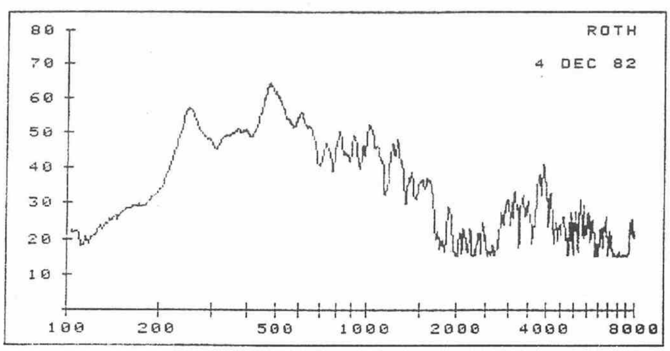

Fig.5. Plot made by fast Fourier transform of a single tap on the bridge. The analog to digital converter recorded 4096 12-bit amplitude readings at 20 microsecond intervals.

After a complete run, the host computer converts the information to decibels, averages and saves the maximum for each filter, converts periods to musical pitches and stores the result on a floppy disc. Each data block occupies about 12 kilobytes, or about 35 kilobytes for the three microphones. Other programs are used to display the data and plot frequency response. Inasmuch as means exist to plot a separate graph for each note as received by each microphone, 96 in all, some simplification is in order.

5. Data Analysis

It will be appreciated that so much data can be examined and displayed in many ways; the possible variations have not been fully exploited, even yet. However, the philosophy of information presentation demands that various

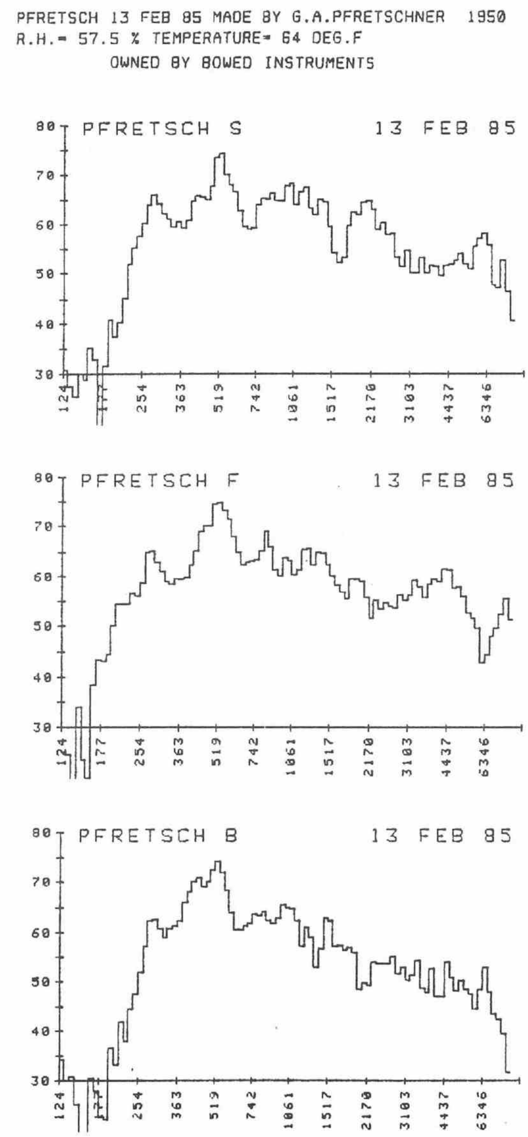

Fig.6. Plots made with 94-channel digital filter and microphones at side, front and back of violin. The bridge was tapped 94 times. Note reduced high and low frequency output from back and differences, especially at high frequencies, between side and top spectra.

levels of detail be available, depending on the use to be made of them. The immediate presentation consists of four histograms on a single sheet, plotting the maximum levels reached in each filter band at each microphone, and an average of the maxima of all data taken for that run. (Fig.8) A listing of numerical values, in relative decibels, is also printed. A practised eye can immediately see the "quality" of an instrument from this presentation, but a further step makes things a lot clearer: A second histogram plots the differences between a given set of data and that obtained under identical conditions for an average of twenty good violins. This has proven to be the most useful display, for a "quick look" as well as detailed study. It has been possible to see quite clearly how exceptionally good instruments differ from the average, and certain characteristics are present in all of the violins considered outstanding by all concerned. (Figs.9-12)

The most conspicuous differences in outstanding instruments are in the 440-550 Hz. segments, where the output is considerably higher than average, and in the fact that from about 2 to 12 kHz. the levels at any of the three microphones do not deviate from the average nor from each other by more than 2 or 3 dB. At frequencies below 440 Hz. violins may show an average difference of 1 or 2 dB from the mean and still be rated high; this affects the tonal judgement in terms of "bright" (slightly under) or "dark" (slightly over). Differences greater than 2 or 3 dB. at the low frequencies bring forth comments such as "tubby" and "thin".

Plans are under way for controlled tests in which spectral response measured this way will be compared with a large number of judgements by qualified listeners and players on a number of instruments, old and new. Work done so far has shown that acoustically inadequate violins can readily be detected; among the good ones, there is a range of values not yet clearly related to player or listener preference. Obviously, there is no one spectral type which satisfies all tastes, but it does seem certain that some characteristics are clearly objectionable and that others are necessary for acceptable tone quality. There is also the interesting question of possible generic differences between old and new violins.

6. Acknowledgements

W. S. Gorrill provided some of his fine violins for repeated testing during the many years of this development. Alan DeVilbiss of Hewlett-Packard Company designed and built what was then a state-of -the art analog to digital converter with fast memory and computer interface. We are grateful to them, and to the many violinists who played their instruments into our microphones and permitted us to tap bridges.

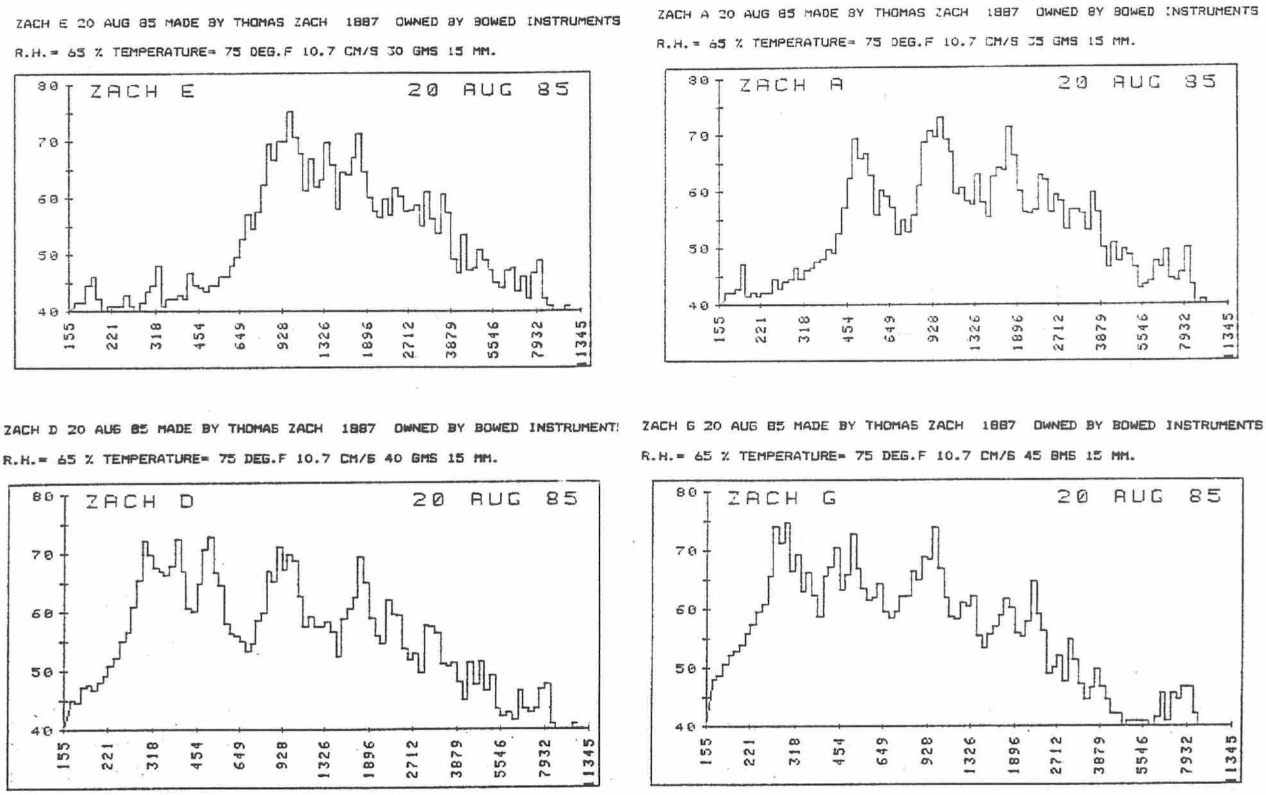

Fig.7. Plots made by machine bowing one string at a time, with single microphone through 94-channel filter. Figures at top show test conditions, including bow velocity, weight and distance from bridge. Roller mechanism shortened string slowly over one and one-half octave range. The maximum output for each filter is plotted.

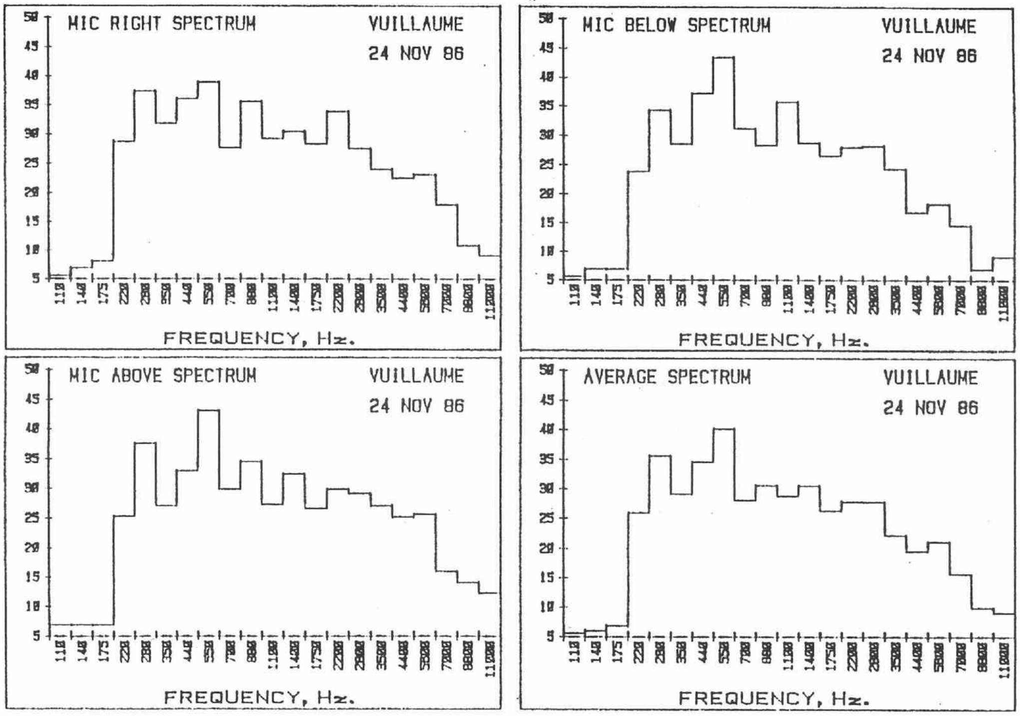

Fig.8. 1/3 octave spectra for one instrument. Microphones located 15 inches away to the right, below and above the violin as it is played. Lower right is the average of all data, not an average of the previous three graphs.

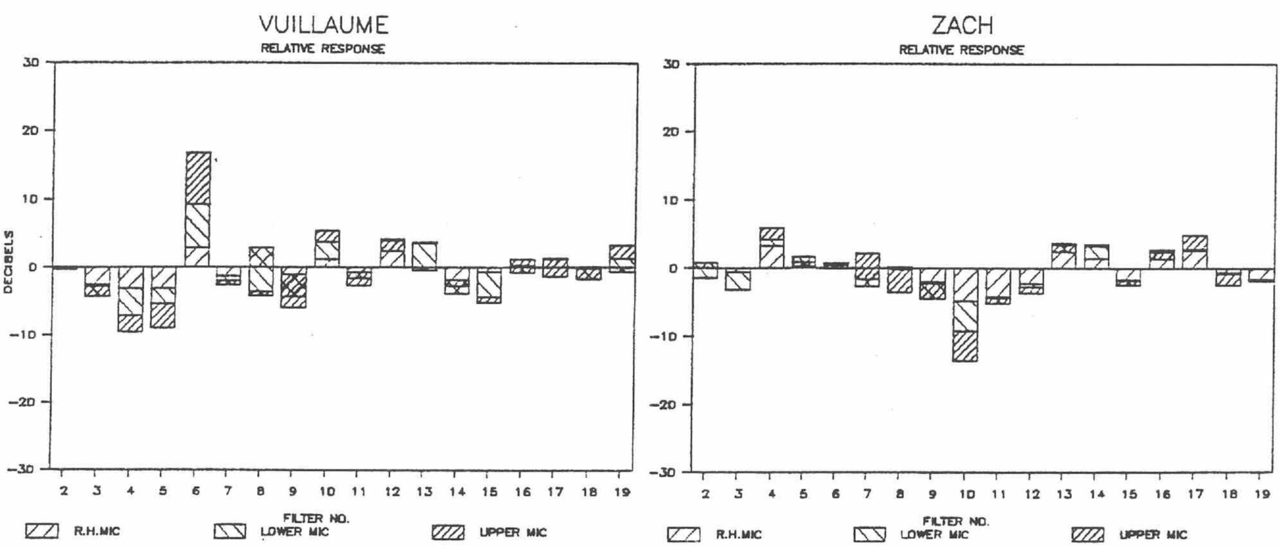

Fig.9. A powerful violin by a great maker with a bright treble sound and smooth high frequencies.

Fig.10. A violin by the "Viennese Strad", Thomas Zach. Rich lows and smooth highs, but not bright enough for a solo instrument.

Figs.9-12. Final graphical presentation made by the new analyzer. The filters are numbered and the following table gives corresponding frequencies:

2	220	8	880	14	3500
3	280	9	1100	15	4400
4	350	10	1400	16	5600
5	440	11	1750	17	7000
6	560	12	2200	18	8800
7	700	13	2800	19	11000

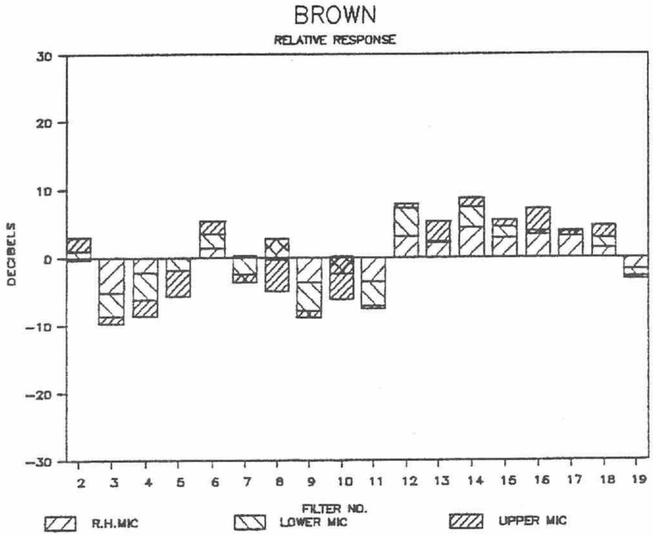

Fig.11. A modern violin with a bright, somewhat thin tone.

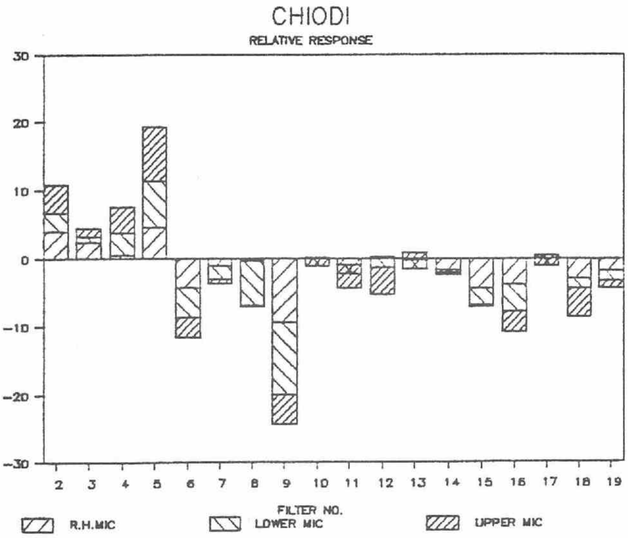

Fig.12. A 1795 Italian of great beauty. Unfortunately, many repairs and possible tampering with thicknesses have weakened the plates. The tone is dark and tubby and weak in middle and high registers.

* * * * *

SOME NOTES ON FREE PLATE TUNING FREQUENCIES FOR VIOLINS, VIOLAS AND CELLOS

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In the last several years, many violin makers have reported the successful use of the free plate tuning method as described in the Catgut Acoustical Society Newsletter # 39 [1]. The report in Journal # 46 by Mr. Sie Anton gives details indicating that the "double octave tuning" (modes #2 and #5 at matching frequencies and an octave apart in both top and back free plates) results in violins with "good resonance, evenness on all four strings, clean and clear tone, good dynamics, sonorous".[2] Anton also indicates that different frequency levels for these "double octaves" result in violins with different bowing characteristics:

X mode #2	O mode #5	
165Hz	330Hz	"soft bowing players and students"
170Hz	340Hz	"chamber players, orchestra players, teachers"
180Hz	360Hz	"soloists and players of exceptional bowing techniques."

We have other reports from violin makers that violins with the X mode #2 at 185Hz and the O mode #5 around 370Hz are also preferred by players with exceptional bowing techniques. These findings are similar to ours. In addition, we find that when mode #2 is at the same frequency in both top and back free plates in the range of 180 -185Hz, a fine violin results even though mode #5 is not exactly an octave above, nor matching in frequency in top and back. Also, instruments with plates tuned in the "matching double octaves" around the 185-370Hz range sometimes have a slightly harsh tone at first which has been found to smooth out with continued playing.

The free top and back plates of the concert Stradivarius known as the "WIRTH" violin which Rembert Wurlitzer loaned me for tests some years ago had the "double octaves" match with modes #2 at 180Hz and #5 at 360Hz.[3]

AN APPARENT ANOMALY

When working for the "double octaves" plate frequency match of modes #2 and #5, a surprising phenomenon sometimes occurs. Suddenly the nodal pattern of either mode #2 or #5 will disappear and glitter jumps into four small spots, two in the upper and two in the lower plate areas. These spots are where the nodal lines of modes #2 and #5 intersect. It is well to mark the spots for they are the best holding points when tapping and listening for the clear full ring of the combined sounds of modes #2 and #5 in a free plate. The phenomenon occurs when the two modes are exactly an octave apart. Even though the vibrations in violin shaped plates are essentially linear, there is enough non-linearity in most loudspeakers to cause vibration at two frequencies an octave apart, especially at high amplitudes. A slight change in the frequency of either mode #2 or #5 and the phenomenon will disappear.

NOTE
A mode match is considered good when the two frequencies lie not more than 1.4% of frequency apart.

AO - BO MODE MATCHING

Here we are dealing with two of the modes in the finished instrument, the so-called "Helmholtz" air mode (AO) around 270-280Hz and a neck-body mode (BO) which lies nearby in frequency, sometimes higher, sometimes lower and sometimes matching.[4] If a violin does have a somewhat harsh tone, it is wise to check the frequency relation of these two modes.[5] When these two modes can be adjusted to have the same frequency[6] the sound of the violin usually smooths out and loses the harsh tone quality on the upper strings. This harshness can also be adjusted to a certain extent by bridge tuning.[7]

TOO MUCH MODE MATCHING?

Importance has been placed on the frequency relationship of modes #2 and #5 in free plates and adjusting their frequencies to be in "matching octaves" in top and back[8]. I have reported that when mode #2 and mode #5 are an octave apart in the top plate, mode #1 usually lies about an octave below mode #2 in frequency; while mode #1 frequency in the back plate is anywhere from 10 to 20Hz higher than in the top[9]. This arrangement of mode #1 frequency being an octave below that of mode #2 in the top plate and less than an octave below in the back plate has almost always occurred without special tuning effort, especially when modes #2 and #5 are in matching octaves and when standard violin making practice in plate graduations is observed.

In the past I have often wondered if even better instruments might result if all three mode frequencies, #1, #2 and #5 were in matching octaves in top and back plates. We now have at least one example indicating that this arrangement of "triple octaves" matching is <u>too much matching</u>!

A normal 16 inch viola had its spruce top and maple back tuned to matching octaves. When it was assembled and strung up, the tone quality was so harsh as to be almost unplayable. It was rejected by all who tried to play it. After letting it sit around for several years with no improvement, I took the top and back plates off and tested them. To my surprise modes #1, #2 and #5 were at matching frequencies in BOTH top and back plates! Apparently, the student, who tuned these plates originally as part of an experiment, had made the center of the back so thin that mode #1 was an octave below mode #2 in the back plate as well as in the top plate. Without further documentation, however, we do not have real proof that this "triple octave mode match" caused the undue harshness in this viola. Just possibly this harshness in the "triple octave mode matched" viola is due to lower damping (higher Q) than we are accustomed to in violas. Appropriate tests for measuring this change in overall damping have not yet been done. This viola is, however, the only one of over 100 violas which has this plate modal characteristic and the only one not having good tone and playing qualities.

MODE FREQUENCIES FOR VIOLA PLATES

Even though we have had many requests for suggested free plate mode frequencies for viola plates, I hesitate to recommend definite frequencies because the sizes and styles of violas vary so greatly, as well as the preferred tonal qualities. However, in my recent group of 12 violas, which players have rated as excellent, I tuned the free plates to have mode #2 at matching frequencies between top and back in the range of 115Hz to 125Hz. The body lengths of these 12 varied from 16¼" to 17¼" and they were of quite different patterns from the slender Stradivarius to the wide, full Gasparo da Salo outlines. In each plate pair mode #5 was also tuned to be at matching frequencies, but I could not get them to have the octave between modes #2 and #5. Only in small violas with nearly violin proportions have I been able to get the octave relationship between modes #2 and #5 in both plates.

MODE FREQUENCIES FOR CELLO PLATES

In the course of tuning the free plates of over a dozen cellos, I find that mode #2 at 60-65Hz and mode #5 at 120-130Hz, with mode #2 always at the same frequency in top and back, result in the best instruments. Cellos with free plate modes around 70 to 140Hz have in general not been as flexible in their playing characteristics or sound qualities.

TUNING FOR MODE #1

In tuning many pairs of free plates of violin family instruments (over 200) I find it most important to so graduate the plate pairs that mode #2 matches in frequency between top and back for a given instrument. (Mode frequencies for the OCTET instruments can be found in CAS JOURNAL # 45.[10] Also, I try to achieve a frequency match of the #5 mode in the plate pair, but if the octave relationship is not possible because of shape, archings or wood characteristics, a higher or lower than the octave match of mode #5 frequencies gives good results.

I do not usually tune especially for the relation of mode #1 an octave below mode #2 in the top, for if the top plate has been properly graduated and the bassbar tuned[11], the mode #1 frequency usually falls nicely about an octave below that of mode #2. In the back plate, if the center is left thick enough (4½ - 5½mm for violins and violas) mode #1 will be 10-20Hz higher than the octave below mode #2, which is apparently desirable.

The cello is the only instrument in which it seems desirable for the frequency of mode #1 in the back plate as well as in the top to be nearly an octave below that of mode #2. In other words, the "triple octave match" of frequencies in a pair of cello plates MAY BE desirable. In tuning cello plate pairs, I have noticed that the modes #2 and #5 at matching octave frequencies,

those of mode #1 are often nearly an octave below those of mode #2! I was worried about this at first, but it seems that the more nearly is the "triple octave" relationship achieved in BOTH top and back CELLO plates, the better the resulting cello!

Such a result from the "triple mode match" is probably due to the increased damping of the larger inside air mass of the cello as compared to that of the violin and viola. Thus the unpleasant harshness that resulted from the "triple mode match" in the viola described above would tend to give in the cello a "brighter" sound rather than undue harshness.

This finding is only partly documented, so it is offered as a mode relationship to watch for. Further documentation and feedback from violin makers, especially on cello plate tuning frequencies of modes #1, #2 and #5 would be most appreciated.

In all the above discussion of mode frequencies it must be remembered that there are three parameters of importance in plate tuning: frequency, amplitude and damping of a given mode. In the work to date it seems that frequency is the most important for mode #2, while amplitude and damping are especially important for mode #5. An estimate of the amplitude can be made from the particle bounce and its relative height. Damping can be judged approximately from the narrowness of the nodal lines of mode #5 - the narrower, the lower the damping, or the longer the ring of the plate when tapped.

In an effort to help bridge the gap between the violin maker and the acoustician, I am continually experimenting with the parameters of instrument construction which can be documented in the hopes of providing the violin maker with some measurable results that can aid in making better instruments, and of giving the acoustician clues for the direction of further meaningful research. The findings described here are offered in this spirit. INFORMATION FROM OTHER MAKERS TO AID IN DOCUMENTATION IS URGENTLY REQUESTED!

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Note: These references can also be found in *Acoustics for the Violin Maker, Vols. I and II.*

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FOURTEENTH ANNUAL VIOLIN CRAFTMANSHIP SUMMER INSTITUTE, June 8 through August 21, 1987. On the campus of the University of New Hampshire, Durham, New Hampshire. Instruction provided by four world renowned master craftsmen: Karl Roy, Director, Bavarian State School of Violin Making, Mittenwald, West Germany; Hans Nebel, William Salchow and Arnold Bone. Seminars and workshops to be offered at the Institute include: Bow Making (in two sessions; June 8-19 and June 22-July 3); Basic Bow Maintenance and Repair Workshop (June 29-July 3); Seminar on the Basics of Violin Maintenance and Minor Repair (July 6-10); Seminar on Violin Repair for Craftsmen (July 13-17); Workshop in Advanced Violin Repair: Crack Repair (July 20-24), and four one-week sessions of Violin Building and Varnishing (July 27-August 21). All seminars and workshops suitable for stringed instrument musicians or music educators. Rolling admissions process, space limited. Applicants are urged to apply early. For an application and descriptive brochure, contact the 1987 Violin Craftsmanship Institute at the University of New Hampshire, Division of Continuing Education, 24 Rosemary Lane, Durham, N. H. 03824; or call (603) 862-1088 between the hours of 8 a.m. and 4:30 p.m. E.S.T. Monday through Friday.

VARIETIES OF RESONANCE WOOD AND THEIR ELASTIC CONSTANTS

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INTRODUCTION

The preferred woods for stringed instruments for violin family manufacture are the straight grained spruce (Picea abies L.) for the top and the pronounced flame across the grain maple (Acer pseudoplatanus L.) of European origin, for the back. If we wish to characterize by one word the spruce resonance wood, we require a very regular structure and obviously high quality of this material. No doubt, for violins, the matching of spruce and maple is the result of a long listening and aesthetic experience of luthiers, that was later verified objectively by fine measurements. The high quality design in stringed instruments appears to be a nice example of compatibility, from the aesthetical point of view, between the form, the function and the materials used by violin makers. Acoustically, spruce and maple are more compatible than other wood species for violin components.

Moreover, the physical characteristics of wood must lie within a narrow range of material's physical constants (elasticity, density, etc.). Variations in these characteristics are the principal determinents of resonance wood quality. Studies (Hutchins, 1981) entailing work on fine instruments stated that carefully selected spruce of both European and American varieties can be employed successfully. Also various aspects of American maple can serve effectively for violin backs. A major question in the use of resonance wood concerns the elastic properties of individual members. This difficulty would vanish if each member could be rated to its own elastical quality, through the use of a nondestructive test.

An excellent review of the literature on methodology of elastic constants measurements on wood is reported by McIntyre and Woodhouse (1986). They underlined the necessity of measuring 18 constants (nine related to pure elastic behaviour and nine to the visco-elastic behaviour) for every wood species.

The motivation for the present study arose from the necessity of achieving the goal of estimating the nine elastic constants of resonance woods of various origin, using the ultrasonic velicity method.

THEORETICAL CONSIDERATIONS *

The relationships between the terms of the stiffness matrix and the ultrasonic velocities are given by Christoffel equations:

$$[\Gamma_{ij} - \rho v^2 \delta_{ik}] = 0 \qquad (1)$$

where:

- Γ_{ij} - the Christoffel's stiffness, a function of terms of matrix (C) and of components of unit wave normal $\vec{n}$
- V - phase velocity of plane elastic wave. Subscripts used to distinguish different velocities associated with direction cosines of normal vector
- ρ - density
- δ_{ik} - Kroneker tensor
- I,2,3- principal anisotropic directions of wood or L,R,T.

TABLE 1 : LIST OF SPECIMENS

	SCIENTIF NAME	COMMON NAME	ORIGINATED FROM	TIME OF AGING BY NATURAL DRYING	NO OF SPECIMEN
PICEA SPP.	P. abies (L) Karst = P. excelsa Link	Spruce, Norway Spruce	SWITZERLAND	7 Years - from 1978	P.1
	P. rubens Sarg = P.Rubra (Du Roi)Link	Red Spruce, Yellow Spruce, Eastern Spruce,	U.S.A - VERMONT	10 Years - from 1975	P.2
		West Virginia Spruce	U.S.A - VERMONT	65 Years - from 1920	P.3
	P. sitkensis (Bong.) Carr	Sitka Spruce, Coast Spruce, Fideland Spruce, Yellow Spruce	ALASKA	15 Years - from 1970	P.4
			U.S.A	15 Years - from 1970	P.6
			U.S.A OREGON	30 Years - from 1955	P.7
	P. Engelmannii Parry ex. Engelm	Engelmann Spruce, Silver Spruce, Mountain Spruce	U.S.A COLORADO	Old	P.5
ACER SPP.	A. saccharum. Marsh.	Sugar maple, Hard maple, Rock maple	U.S.A VERMONT	35 Years - from 1950	A.1
			U.S.A NEW HAMPSHIRE	2 Years - from 1983	A.4
	A. rubrum L.	Scarlet maple, Soft maple, Water maple	U.S.A - VERMONT	35 Years - from 1950	A.2
	A. macrophyllum Pursh	Bigleaf maple, Broadhaf maple, Oregon maple	U.S.A - OREGON	15 Years - from 1970	A.5
				15 Years - from 1970	A.6
	A. platanoïdes L.	Maple (Norway)	WEST GERMANY	35 Years - from 1950	A.3
	A. pseudoplatanus L.	Planetree maple, Sycomore maple	FRANCE VOSGES	1 Year - from 1984	A.7

If the eq. (1) is solved for wave propagation along the symmetry axes, we get three solutions that enable us to calculate the 6 diagonal terms of (C) matrix, by a relation presenting the general form:

$$C_{ii} = v^2{}_{ii} \cdot \rho \tag{2}$$

The 3 off-diagonal terms of stiffness matrix can be calculated using the general eq. (3)/:

$$C_{ij} = \Gamma_{ij} / n_k\, n_1 - C_{ii} \tag{3}$$

From this equation we can calculate the velocity $V_{ij} = C_{ij}/\rho$ or the slowness $s_{ij} = 1/\ V_{ij}$

Plots of slowness s_{ij} against the angle of wave vector orientation give the slowness surfaces.

In the interest of clarity we illustrate the use of the analysis given before for the plane 12. The off-diagonal term C_{12} is:

$$C_{12} = V_{12} : \rho = n_1 \,.\, n_2 [(C_{11} . n_1^2 + C_{66} . n_2^2 - \rho V^2) \tag{4}$$

$$(C_{66} . n_1{}^2 + C_{22} . n_2{}^2 - \rho V^2)]^{1/2} - C_{66}$$

where:

- n_i - components of unit wave normal vector $\vec{n}$
- V - velocity of quasilongitudinal or quasitransversal waves, dependent on the propagation vector and consequently on the orientation of the specimen.

For the other off diagonal terms and for the representations of rotation about the required axis, the eq. (4) must be modified by cyclic interchange of subscripts.

Experimentally, we obtain for every orientation angle of specimen two velocities, one corresponding to the quasilongitudinal displacement vector and another with the quasitransversal displacement vector. If we draw attention to the association of all measured values of velocities, we can compute invariants in every plane as:

$$v = (V_{QL}{}^2{}_\theta + V_{QT}{}^2{}_\theta + V_Q{}^2{}_{L\theta'} + V_Q{}^2{}_{T\theta'})^{1/2} \tag{5}$$

where:

The velocity invariants insensitive to the choice of coordinates, give a concise presentation of voluminous experimental data. In every orthotropic plane this constant provides useful physical insight into wood parameters and is a viable compact form for documentation about the acoustical properties of species and for subsequent retrieval in engineering applications, as the measurements of grain angle on living trees.

As one would expect, we focus our attention on the principal goal of this work, the computation of Young's moduli and Poisson's ratios from ten redundant measurements. It is well known that each measured velocity leads to a calculated value C_{ij} . For the calculation of technical constants, (C) is converted in (S) matrix. The elastic moduli are the reciprocals of the principal diagonal coefficients of compliance matrix. Our choice of the technical constants was made by selecting those combinations of values corresponding to the highest E_L modulus.

* materials summarized in reference works: Auld, 1973, Musgrave, 1970.

TABLE 2 : ULTRASONIC VELOCITIES OF PICEA (SPP) and ACER (SP) AT 1 MHZ MEASURED IN PRINCIPAL DIRECTION OF WOOD (Average values).

SPECIES		SPECIMEN NO	DENSITY Kg/m³	VELOCITIES (m/s)					
				$V_{11} = V_{LL}$	$V_{22} = V_{RR}$	$V_{33} = V_{TT}$	$V_{44} = V_{TR}$	$V_{55} = V_{LT}$	$V_{66} = V_{LR}$
RESONANCE SPRUCE (Picea spp.)	P. Abies	P.1	400	5050	2000	1600	300	1425	1375
	P. Rubens	P.2	400	5351	2192	1732	325	1325	1420
		P.3	485	6000	2150	1600	330	1240	1320
	P. Sichensis	P.6	370	5600	2150	1450	300	1340	1400
		P.7	430	5500	2300	1500	350	1480	1500
		P.4	437	5481	2178	1530	340	1300	1487
	P.Engelmannii	P.5	352	5500	2225	1850	325	1386	1361
FIDDLEBACK MAPLE (Acer spp.)	A.Pseudoplata.	A.7	670	4600	2500	1870	925	1530	1835
	A. Platanoides	A.3	740	4940	2491	1942	987	1360	1698
	A.Macrophyllum	A.6	600	4500	2340	1550	900	1340	1720
		A.5	625	4560	2000	1402	750	1330	1700
	A. Saccharum	A.1	700	4785	2376	1786	653	1352	1736
		A.4	720	4560	2300	1400	900	1380	1730
	A. Rubrum	A.2	560	3800	2510	1850	740	1450	1750

Indeed now it is pertinent to ask whether the values of Young's moduli so determined are in agreement with measurements. Velocities or slowness surfaces are able to check the validity of this procedure, by fitting the values of C_{ij} used for the calculation of E_L (considered as optimum) in eq. 6, or similar for the planes 13 and 23:

$$\begin{vmatrix} \Gamma_{11} - \rho V^2 & \Gamma_{12} \\ \Gamma_{12} & \Gamma_{22} - \rho V^2 \end{vmatrix} = 0 \qquad (6)$$

and compare them with experiments. The agreement between them is a test of the validity of the calculation.

MATERIALS AND METHOD

We report the results of a study of woods selected for the primary components of high quality stringed instruments on species listed in table 1. Measurements were performed on cubic specimens of 16mm using a classical transmitting pulse technique, described in the pages of thie Journal (Bucur, 1985). For every species 15 cubes were used, three in principal directions of wood symmetry and 12 out of axes. The specimens were conditioned at 10±2% moisture content.

RESULTS

The results are summarized in tables 2...8. Six ultrasonic velocities measured in principal orthotropic axes are given in table 2. Moreover, these velocities lie within a narrow range of values. If we compare this result with the Barducci and Pasqualini (1948) data, it is evident that the resonance woods (Picea spp. or Acer spp.) estimated versus ordinary coniferous or broadleaved species have the highest values of V_{LL} (fig. I). Without doubt on this graph it seems that a low density can be regarded as a telling criterion for the selection of species having a high velocity in longitudinal direction.

Furthermore, the terms of the stiffness matrix were calculated using the values of velocity in axes and out of them following the optimisation procedure described above.

Plots of slowness against the angle of wave orientation using the optimised values of elastic constants that gives the slowness surfaces are shown in figure 2. The agreement between the theoretical and experimental values is reasonable for quasilongitudinal waves and less favorable for quasitransversal waves. Variations in those data are due to two principal sources: the instrumentation accuracy as well as the inherent sample to sample variability.

In addition to the slowness surface, the velocities ratios can give an idea about the anisotropy of every wood species. Three ways of expressing anisotropy (tables 3,4) were chosen:

a) the ratios between measured longitudinal velocities in axes,
b) the ratios between measured transversal velocities in axes,
c) the ratios between measured velocities in a) and b),
d) the ratios between velocities measured on b) and the calculated transvers velocities on axes
e) the ratios between invariants in symmetry planes.

The implications of results are for the most part self evident. The average ratios between longitudinal velocities, when V_{11} is considered as the reference velocity, for spruce are 1:2.5:3.5 and 1:1.9:2.8 for maple. For transversal velocities when V_{66} is the reference velocity, the ratios are: 1:0.9:4.4 for Picea spp. and 1:1.2:2.1 for Acer spp.

The ratios between the quoted velocities and the density are more or less in the same range as the results mentioned before.

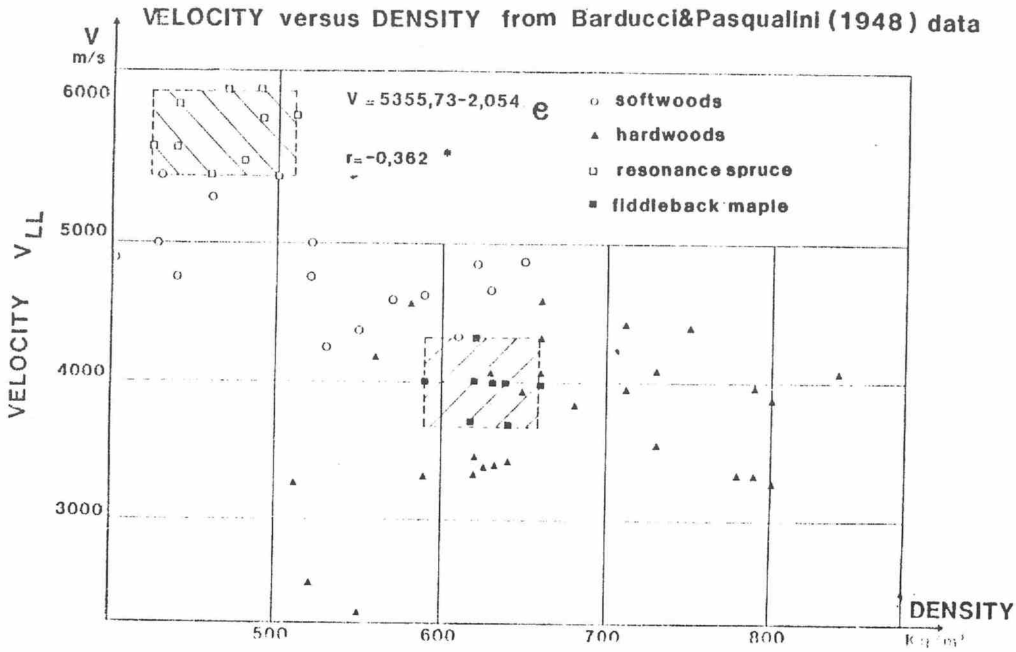

Figure I: Velocity versus density (from Barducci, Pasqualini, 1948)

Another attractive idea is to consider the velocity V_{11} as a reference for all velocities measured in axes and to corroborate it with V_{22}, $V_{33} \ldots V_{66}$.

This calculation gives the following ratios:

Picea spp. 1:2.5: 3.4:16.9 : 4.0:3.9
Acer spp. 1:1.9: 2.7: 5.4 : 3.2:2.6

We note that the most important difference between Picea spp. and Acer spp. is shown by the ratios $V_{11}:V_{44}$, respectively 17 to 5.

However, having in mind these results, the wood anisotropy could be expressed efficiently in a simpler manner by the ratio between the maximum longitudinal velocity and the minimum sheer velocity in axes. On the other hand, we have already noted that the anisotropy can be also expressed by the ratio $V_{QT}:V_T$ (table 3). This expression shows the high symmetry of Picea spp. in the planes 12 and 13 (LR or LT) versus the transverse one 23 (or RT) and at the same time the high anisotropy of planes 12 and 13 versus 23 plane. Using the same agrument for Acer spp., we can state that the anisotropy of this wood is two times less important than that of spruce. The same conclusion arises from the calculations of invariants (table 4), that take into considerations all velocities.

The elastic constants for wood species studied, calculated according to the optimisation procedure chosen in this paper are summarized in tables 5, 6 and 7. The units are $10^8 N/m^2$ for stiffnesses and technical constants and $10^{-11} m^2/N$ for compliances. The Poisson's ratios, ν, | are obtained from compliance S_{ij} as $\nu_{ij} = -S_{ij}:E_j$ as cited by Bodig and Goodman (1973) and Hearmon (1948). Our results are in agreement with data in the literature (table 8).

All results discussed here relate the measurements of wood ultrasonic velocity and implicitly the elastic constants to the continuum theory which ignores the periodic structure of this material. The local properties of wood, well revealed by the microdensitometric analysis are not considered. One promising research line to follow in the future is to investigate the local elastic response in relation to the macroscopic behavior of this solid, having in mind that wood is a piezoelectric material.

CONCLUSION

The ultrasonic pulse technique described herein is suitable for studying the elastic behavior of wood. The symmetry and the anisotropy of this material can also be examined. For the complete description of wood species analyzed, further research may lead to the computation of nine imaginary parts of complex moduli.

ACKNOWLEDGMENT

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Finally we must mention the help of our colleague P. Gelhaye in preparing the numerous specimens needed in this study.

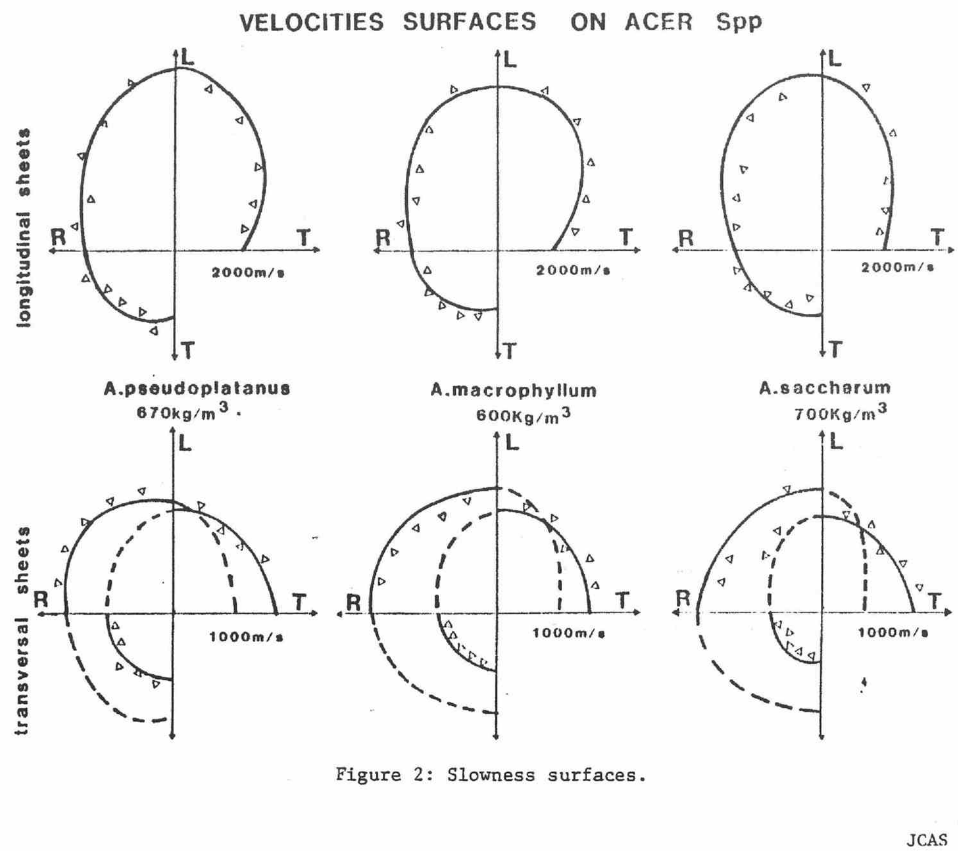

Figure 2: Slowness surfaces.

TABLE 3 : WOOD ANISOTROPY IN TERMS OF ULTRASONIC VELOCITIES.

	SPECIES	SPECIMEN NO	DENSITY Kg/m^3	RATIOS BETWEN VELOCITIES : LONGITUDINAL $V_{11} : V_{22} : V_{33}$	RATIOS BETWEN VELOCITIES : TRANSVERSAL $V_{66} : V_{55} : V_{44}$	ANISOTROPY AS V_{QT} / V_T PLANE 12 0°	PLANE 12 90°	PLANE 23 0°	PLANE 23 90°	PLANE 31 0°	PLANE 31 90°
RESONANCE SPRUCE (Picea spp.)	P. Abies	P.1	400	1 : 2,5 : 3,2	1 : 1,0 : 4,5	0,98	4,49	0,21	0,22	5,00	0,98
	P. Rubens	P.2	400	1 : 2,4 : 3,3	1 : 0,9 : 4,4	1,09	4,28	0,20	0,27	4,29	0,88
		P.3	485	1 : 2,8 : 3,8	1 : 1,1 : 4,0	1,08	3,94	0,20	0,32	3,92	0,89
	P. Sitchensis	P.6	370	1 : 2,6 : 3,9	1 : 0,9 : 4,7	1,09	4,49	0,21	0,24	4,49	0,96
		P.7	430	1 : 2,4 : 3,7	1 : 0,9 : 4,3	1,07	4,09	0,21	0,27	4,19	0,99
		P.4	437	1 : 2,5 : 3,6	1 : 0,8 : 4,4	1,14	4,05	0,19	0,29	3,59	0,93
	P. Engelmannii	P.5	352	1 : 2,5 : 3,0	1 : 1,0 : 4,2	1,00	4,11	0,20	0,27	4,26	1,04
FIDDLEBACK MAPLE (Acer spp.)	A.Pseudoplatanus	A.7	670	1 : 1,8 : 2,5	1 : 1,2 : 2,0	1,19	1,98	0,51	0,59	1,67	0,83
	A. Platanoides	A.3	740	1 : 1,9 : 2,5	1 : 0,8 : 1,7	1,24	1,73	0,58	0,73	1,49	0,73
	A.Macrophyllum	A.6	600	1 : 1,9 : 2,9	1 : 1,3 : 2,0	1,28	1,94	0,48	0,72	1,49	0,78
		A.5	625	1 : 2,3 : 3,3	1 : 1,3 : 2,3	1,27	2,29	0,45	0,56	1,78	0,78
	A. Saccharum	A.1	700	1 : 2,0 : 2,7	1 : 1,3 : 2,7	1,28	2,67	0,38	0,48	2,05	0,79
		A.4	720	1 : 1,9 : 2,5	1 : 1,3 : 1,9	1,26	1,97	0,55	0,72	1,53	0,79
	A. Rubrum	A.2	560	1 : 1,5 : 2,0	1 : 1,2 : 2,4	0,51	2,42	0,43	0,50	1,91	0,84

TABLE 4 : VELOCITIES INVARIANTES

	SPECIES	SPECIMEN NO	DENSITY Kg/m^3	VELOCITIES INVARIANTES (m/s) PLANE 12	PLANE 23	PLANE 13	ANISOTRPY OF INVARIANTES RATIOS IN 3 PLANES
RESONANCE SPRUCE (Picéa SPP.)	P. Abies	P.1	400	5768	2596	5667	1 : 2,22 : 1,02
	P. Rubens	P.2	400	6120	2830	5927	1 : 2,16 : 1,03
		P.3	485	5642	2720	6452	1 : 2,44 : 1,03
	P. Sitchensis	P.6	370	6316	2116	6127	1 : 2,98 : 1,03
		P.7	430	6327	2790	6072	1 : 2,27 : 1,04
		P.4	437	6260	2703	5976	1 : 2,32 : 1,05
	P. Engelmannii	P.5	352	6237	2928	6124	1 : 2,13 : 1,02
FIDDLEBACK MAPLE (Acer SPP.)	A.Pseudoplata	A.7	670	5657	3384	5410	1 : 1,67 : 1,05
	A. Platanoide	A.3	740	6030	3451	5646	1 : 1,74 : 1,07
	A.Macrophyllum	A.6	600	5624	3081	5122	1 : 1,82 : 1,09
		A.5	625	5529	2664	5128	1 : 2,07 : 1,08
	A. Saccharum	A.1	700	5878	3105	5453	1 : 1,89 : 1,08
		A.4	720	5663	2978	5177	1 : 1,90 : 1,09
	A. Rubrum	A.2	560	5203	3287	4696	1 : 1,58 : 1,10

N.B. - The invariant of velocities in every plane is calculated with the following relationship :

$$\bar{V} = \left[V^2_{QL\,\alpha} + V^2_{QT\,\alpha} + V^2_{QL\,(90-\alpha)} + V^2_{QT\,(90-\alpha)} \right]^{0,5}$$

TABLE 5 : TERMS OF STIFFNESS MATRIX $/\times 10^{8}\ N/m^2/$

	SPECIES	SPECIMEN NO	DENSITY Kg/m^3	DIAGONAL TERMS						OFF DIAGONAL TERMS			CUBIC COMPRESSIBILITY
				C_{11}	C_{22}	C_{33}	C_{44}	C_{55}	C_{66}	C_{12}	C_{13}	C_{23}	$C_{11}+C_{22}+C_{33}+2(C_{12}+C_{13}+C_{23})$
RESONANCE SPRUCE (Picea spp.)	P. Abies	P.1	400	102,01	16,00	10,24	0,36	8,12	7,56	17,53	13,20	12,14	213,99
	P. Rubens	P.2	400	114,53	19,22	11,99	0,42	7,02	8,06	29,08	23,29	13,90	278,28
		P.3	485	174,60	22,44	12,42	0,53	7,45	8,46	22,98	16,43	15,46	319,18
	P. Sitchensis	P.6	370	116,03	17,10	7,78	0,33	6,64	7,25	14,97	10,26	7,57	206,51
		P.7	430	130,07	22,75	9,77	0,53	9,42	9,68	25,66	19,34	10,81	274,11
		P.4	437	131,30	20,70	10,23	0,51	7,38	9,66	27,75	22,25	13,39	289,01
	P. Engelmannii	P.5	352	106,48	17,43	12,04	0,37	6,76	6,52	26,91	20,79	14,13	259,61
FIDDLEBACK MAPLE (Acer spp.)	A. Pseudoplatanus	A.7	670	141,34	41,87	23,43	5,73	15,68	22,56	32,49	30,72	18,53	370,12
	A. Platanoides	A.3	740	180,59	45,91	27,90	7,20	13,68	21,34	54,17	43,70	16,26	482,66
	A. Macrophyllum	A.6	600	121,50	32,85	14,42	4,86	10,77	17,75	12,65	11,39	8,39	233,63
		A.5	625	129,96	25,00	12,28	3,52	11,06	18,06	15,18	12,64	8,72	240,32
	A. Saccharum	A.1	700	160,27	39,52	22,33	2,82	12,79	21,09	43,47	32,19	20,38	414,20
		A.4	720	149,71	38,09	14,11	5,83	13,71	21,55	24,09	23,92	13,76	325,45
	A. Rubrum	A.2	560	80,86	35,28	19,16	3,06	11,77	17,15	11,50	14,49	12,78	212,84

TABLE 6 : TERMS OF COMPLIANCE MATRIX $(\times 10^{-11}\ m^2/N)$

	UNITS	RESONANCE SPRUCE (Picea spp.)							FIDDLEBACK MAPLE (Acer spp.)						
		P. Abies	P. Rubens		P. Sitchensis			P. Engel.	A.Pseudo	A.Plata.	A.Macrophyllum		A. Saccharum		A.Rubrum
		P.1	P.2	P.3	P.6	P.7	P.4	P.5	A.7	A.3	A.6	A.5	A.1	A.4	A.2
DENSITY	kg/m3	400	400	485	370	430	437	352	670	740	600	625	700	720	560
S_{11}	$10^{-11}\ \frac{m^2}{N}$	12,07	14,73	6,63	10,00	11,13	12,15	16,09	10,24	11,16	8,99	8,70	9,58	9,16	14,33
S_{22}	"	638,63	328,59	319,07	105,35	95,36	317,34	1180,00	37,66	34,38	36,16	54,12	52,15	40,54	37,44
S_{33}	"	972,63	536,16	569,12	232,52	248,24	728,82	1780,00	77,34	58,85	85,39	113,74	91,15	134,82	76,05
$-S_{12}$	"	14,13	9,86	5,27	5,13	4,22	-5,26	- 3,79	3,06	8,79	1,94	2,87	6,45	2,83	9,82
$-S_{13}$	"	1,18	17,17	. 2,19	8,21	17,54	33,30	35,34	10,88	12,37	5,97	6,92	7,92	15,26	10,18
$-S_{23}$	"	-738,91	361,77	390,18	95,75	98,17	426,79	139,00	25,78	6,25	19,48	35,47	38,29	39,06	24,00

N.B. - The Poisson's ratios can be calculated as : $S_{ij} = -\frac{\nu_{ij}}{E_i}$ or $S_{ij} = -\frac{\nu_{ij}}{E_j}$

because both expressions are listed in the litterature (HEARMON, 1948 ; BODIG, 1973)

The calculated Poisson's ratios must satisfied the following relationship $1 - \nu_{ij} \cdot \nu_{jk} > 0$.

If this relation is not satisfied, the values must be rejected and an other optimisation procedure accepted for the terms S_{ij}.

TABLE 7 : TECHNICAL CONSTANTS

		UNITS	RESONANCE SPRUCE (Picea spp.)							FIDDLEBACK MAPLE (Acer spp.)						
			P.Abies	P. Rubens		P. Sitchensis			P. Engel.	A.Pseudopl.	A.Platanoi.	A.Macrophyllum		A.Saccharum		A.Rubrum
			P.1	P.2	P.3	P.6	P.7	P.4	P.5	A.7	A.3	A.6	A.5	A.1	A.4	A.2
	DENSITY	Kg/m3	400	400	485	370	430	437	352	670	740	600	625	700	720	560
Young's moduli	$E_1 = E_L$	10^8 N/m2	82,79	67,89	150,86	99,95	89,95	82,31	62,11	98,59	89,53	111,20	114,90	104,37	109,14	69,77
	$E_2 = E_R$	"	1,56	3,04	3,13	9,49	10,48	3,15	0,85	26,55	29,08	27,66	18,47	19,17	24,67	19,17
	$E_3 = E_T$	"	1,03	1,86	1,75	4,30	4,02	1,57	0,56	12,93	16,99	11,71	8,79	10,97	7,42	10,97
Shear moduli	$C_{66} = G_{LT}$	"	7,56	8,06	8,46	7,25	9,68	9,66	6,52	22,56	21,34	17,75	18,06	21,09	21,55	17,15
	$C_{55} = G_{LT}$	"	8,12	7,02	7,45	6,64	9,42	7,38	6,76	15,68	13,68	10,77	11,05	12,79	13,71	11,77
	$C_{44} = G_{TR}$	"	0,36	0,42	0,53	0,33	0,53	0,51	0,37	5,73	7,20	4,86	3,52	2,82	5,83	3,06
Poisson's ratios	$\nu_{12} = \nu_{LR}$	-	0,022	0,029	0,016	0,048	0,044	-0,016	-0,003	0,081	0,255	0,054	0,053	0,123	0,069	0,188
	$\nu_{13} = \nu_{LT}$	-	0,001	0,031	0,004	0,035	0,070	0,052	0,019	0,140	0,210	0,069	0,061	0,087	0,113	0,111
	$\nu_{23} = \nu_{RT}$	-	0,761	0,672	0,683	0,411	0, 395	0,670	0,077	0,333	0,106	0,228	0,312	0,420	0,289	0,266

TABLE 8 : TECHNICAL CONSTANTS MEASURED BY HAINES (1979)

	UNITS	RESONANCE SPRUCE (Picea spp.)				FIDDLEBACK MAPLE (Acer spp.)		
		P. Abies	P. Rubens	P. Sitchensis	P.Engelmannii	A. Platanoides	A. Macrophyllum	A. Saccharum
DENSITY	Kg / m^3	390....560	410 ... 590	370 ... 520	400 ... 450	590 ... 750	660 ... 670	610 ... 800
VELOCITY V_{11}	10^3m/s	5,3...6,0	4,8... 6,3	3,7 ... 6,1	5,2	5,7 ... 4,2	3,4 ... 3,8	3,8 ... 4,6
$E_1 = E_L$	10^8 N/m^2	110....170	40 ... 180	53 ... 180	110	68 ... 130	77 ... 96	77 ... 110
$E_2 = E_R$	"	1,7...11	6,2... 14	1,9 ... 13	18	18 ... 25	18	10 ... 26
$C_{66} = G_{LR}$	"	6,3...13	6,3... 12	5,1 ... 12	7,8	12 ... 33	13	13 ... 23
$C_{44} = G_{TR}$	"	0,44..0,72	0,34...1,6	0,27...1,2	1,10	3,9 ... 10	5,7	3,5...8,7

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NEWS, NOTES AND CORRESPONDENCE

This section of the JOURNAL is for member interchange: reports of member activities, letters to the Editor, news of meetings, book and papers published by CAS members in other journals, and interesting notes. Please help to make this YOUR JOURNAL.

* * * * *

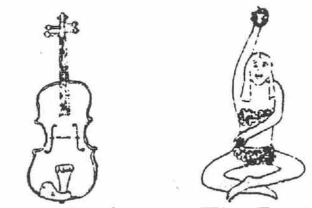
One of our most noteworthy happenings this year is that CAS member Dudley Herschbach, Frank B. Baird Professor of Science at Harvard, received the 1986 Nobel Prize in Chemistry, along with Yuan T. Lee and John C. Polanyi, for the development of the molecular beam method for studying the dynamics of chemical reaction.

An avid quartet player along with his wife Georgene and daughters, Lisa and Brenda (see photo), Dudley and Georgene were jointly Masters of Currier House at Harvard from 1981-1986, where they sponsored many concerts and musical gatherings. Dudley's "Musical Metaphors" are here republished for your delight. (See CAS Newsletter # 31).

Musical Metaphors: The String Quartet

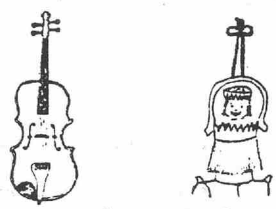
Four Variations on a Theme of R. W. Wood

by Dudley Herschbach



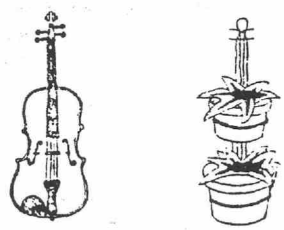
The First Violin — The First Vile Sin

How strange to think sweet, beloved fiddle
May spring from the fateful, satanic apple!
Yet if our first crime was reckless yearning
For godly vision, does not this proud string
Dare that same quest with soulful melody?
Yea, but Heaven applauds this charming felony.



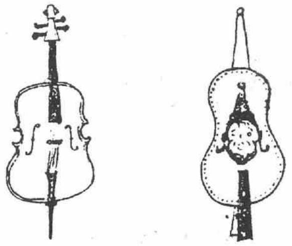
The Second Violin — The Second Smilin'

Hello, do not mistake this shy soprano
For the pale image of its regal friend!
This is not mere echo or dim reflection,
But the hues and harmony of a chameleon.
Ponder well such a wise and mystic role:
First smiles glitter but seconds can turn to gold.



The Viola — The Viola

How akin this dulcet inner voice
To soft, warm glow of velvet bloom!
Just as yon soil wakes seed to magic life
When bid by joyous sun and gentle dew,
The noble alto sprouts its Delphic tones
When coaxed by blithe and eager bow.



The 'Cello — The Bellows

Hail these colleagues, so robust and mellow;
Both puff lush air to rouse flashy fellows!
Just as the accordion pants and purrs
To stir prancing sparks from feeble embers,
The sturdy bass snorts tempo, rhythm, dynamics,
And thus incites puny partners to acrobatics.

Brenda Herschbach playing one of our cellos.

By the time you receive this issue of the JOURNAL we will have had three concerts on the OCTET this year:

February 22, in the Kresge Auditorium of the Massachusetts Institute of Technology, Cambridge, funded by M.I.T. and played by members of the Metropolitan Symphony Orchestra under the baton of Christopher Blair, with Frank Benoit as manager.

March 8, at the Hyatt Regency Hotel, Baltimore, Maryland, for the Annual Meeting of the American String Teachers Association, organized and directed by Frank Lewin:

Treble Violin	Nadia Koutzen	Tenor Violin	Michael Finckel
Soprano Violin	Lisa Brooke	Baritone Violin	Chris Finckel
Mezzo Violin	Ryan Brown	Small Bass Violin	Norman Edge
Alto Violin	Margy Slapin	Contrabass Violin	Derwyn Holder

P R O G R A M

Mass "L'Homme Armé" : Sanctus	Giovanni Pierluigi da Palestrina (arr. Lewin)
Introduction on a Psalm Tune	Frank Lewin
Solo Sonata No. 3: Allegro assai performed on Treble violin	Johann Sebastian Bach
Barytontrio No. 82: Adagio	Franz Joseph Hadyn (arr. C.P.Rogers)
Sonata No. 4 for Two Violas: Allegro moderato performed on Alto and Tenor Violins	Jean-Marie Leclair
Reflections on a Disused Railway Line	Roderick Skeaping
Gymnopédies Nos. 1 and 2	Erik Satie (arr. Lawrence Rackley)
Aphorisms: Brevity is the Soul of Wit Evil Weeds Still Waters When the Cat's Away.. Don in the Manger	Gordon Jacobs

(This concert funded by your contributions)

March 18, at the Douglass College, Nicholas Center, New Brunswick, N. J. with the same performers as the March 8 concert. Sponsored ans funded by the "New Jersey Women's Project".

* * * * *

In addition to the regular work of answering mail, keeping up with additions and changes to our membership list and maintaining our 50 + file drawers of information, the CAS office staff of Elizabeth McGilvray, Barbara McMillan and CMH spent a large part of November, December and January getting out some 1200 fund raising packets for concerts on the VIOLIN OCTET. The 200 + responses to this are very gratifying and we are deeply grateful to our members and friends who responded so generously.

* * * * *

The bass quartet of Roy Cummings, Norman Edge, Derwyn Holder and Ronald Naspo had a session at 112 Essex in February using four of our basses - two large basses and two small basses. This is the first time four of our basses have been heard together and the sounds are unbelievably exciting!!

* * * * *

In November, informal research conferences were held in the D. C. area involving Edith Corliss, Mary Lee Esty, Carolyn Field, Carleen Hutchins and James Trott. In January, Oliver Rodgers spent several days at 112 Essex Avenue with CMH, discussing correlations between practical free plate tuning and finite element simulation of free plate mode characteristics, as an eventual aid to violin makers in tuning plates.

* * * * *

Dr. Thomas W. W. Stewart, Professor of Physics at the University of Western Ontario, interested in the development of Physical Acoustics and in the training of young people, who was an active member of the Catgut Acoustical Society, died July 13, 1986.

He was trained both at the University of Western Ontario and received his Ph.D. at University College, University of London, England. Interested in many athletic sports, Tom was an avid ice hockey player and coach and involved his four children in active sports as well as in music.

An example of his dedication to his students is the story that one summer he gave an entire course for one blind student, preparing all the necessary material in braille. This became the subject of a paper "Getting a Feel for Physics," published in The Physics Teacher.

Tom did some very interesting work on the acoustics of the violin and was an enthusiastic member of the Catgut Acoustical Society.

We shall all miss a good friend.

Harriett M. Bartlett (1897-1987), friend and benefactor of the Catgut Acoustical Society, will be long remembered by many, not only her close friends and professional associates, but others whom she has helped along the way. A graduate of Vassar with a degree from the London School of Economics, an MA from the University of Chicago, and two honorary Doctorate degrees - Boston University and Simmons College - Miss Bartlett spent most of her professional career in Medical Social work, writing six books and over thirty five articles in the field. She received many awards and is known world-wide for her efforts toward the improvement of social work practice and the strengthening of social work as a young and growing profession.

As a close friend with whom my family and I shared our summer home since 1941, we have had a wonderful association. Harriett's belief in and support of what I have been trying to do in violin research and developemtn and in the work of the Catgut Acoustical Society has made many things possible. A great lady has gone.

Carleen M. Hutchins

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Members of the CAS were well represented in the sessionsof the November, 1986 meeting of the Acoustical Society of America in Anaheim, California:

John Backus received the Silver Medal "for pioneering research on the acoustics of woodwind and brass instruments, and for bridging the gap between acousticians and musicians." The two previous recipients of this medal are Carleen M. Hutchins (1981) and Arthur H. Benade (1984).

David Lubman chaired Session A. Architectural Acoustics I and Musical Acoustics I: Acoustical Evaluation of Halls for the Performing Arts. This included papers: Design criteria for acoustical excellance of auditoriums, Paul S. Veneklasen; Critique of certain concert-hall design criteria, A. H. Benade. Carleen M. Hutchins chaired Session J. Architectural Acoustics II and Musical Acoustics II: Acoustical Evaluation of Halls for the Performing Arts. This included paper: User evaluations of the acoustical characteristics of recently completed performing arts halls, Donald L. Engle. CMH was leader of a panel discussion on the subject. Session U 7: Using FFT analyzers in undergraduate physics courses, Thomas D. Rossing. Session E12: A blowdown water tunnel for investigation of tones from multihole plates, S. A. Elder. Herman Medwin co-chaired Session V. Physical Acoustics III and Underwater Acoustics III: This included his paper On shrinking the world's oceans into a physics laboratory. Session Y8: On the controversial leaky Rayleigh wave at a water/ice interface, Jacques R. Chamuel. Session JJ5: Inexpensive microcomputer-based sound measurement apparatus, Roger J. Hanson. Session JJ8: Laboratory and demonstration experiments with guitars, Thomas D. Rossing. William J. Strong chaired Session PP. Musical Acoustics VI: General Topics. This included papers: Acoustical problems in the bassoon, John Backus; Simulation of a player-clarinet system, Scott D. Sommerfeldt and William J. Strong; Science in the service of the performing arts. Section I: Background; Section II: The physical factors; Section III: Experiments with full orchestra and conclusions, Paul S. Veneklasen. Session RR9: Tone Color and spectral spaces for steady sounds, Evi Papachristou, William J. Strong. Session RR12: An auditory paradox, Diana Deutsch. Session SS6: Broadband generalized nearfield acoustical holography, Earl Williams. Session TT11: Modal analysis of the vocal tract, Ian M. Firth. Session UU13: An ultrasonic ranging system for robot position sensing, Fernando Figueroa and John S. Lamancusa. Edith L. R. Corliss chaired Session VV. Musical Acoustics VII: Ethnic Musical Instruments, Part 2: Percussion and Winds. This included papers: Acoustics of Oriental gongs and bells, Thomas D. Rossing; The ancient Chinese "calendrical" pitchpipes, Ernest G. McClain; Primitive musical instruments using Helmholtz resonators, Ian M. Firth; Vibrational modes of a Chinese two-tone bell, H.John Sathoff, B.R.Richardson, D.Scott Hampton, Thomas D. Rossing and André Lehr; Acoustics of Caribbean steel drums, Thomas D. Rossing; Session CCC. Musical Acoustics VIII: Ethnic Musical Instruments, Part 2: Strings: Chaired by Thomas D. Rossing which included papers:Acoustics of the Highland, Irish and Baroque harps, Ian M. Firth; Acoustical studies on p'i-p'a and cheng, Shih-yu Feng. Session DDD7: Using nearfield acoustical holography to analyze a source excited by multiple frequencies, William Y. Strong, Jr. Session FFF1: Annoyance of moderate level of noice spectra with predominating pure tones, Gordon R. Bienvenue, Brian Wood, Susan R. Glass and Robert D. Celmer.

As cellist of the now famous Emerson Quartet, David Finckel shares in their 10th anniversary celebration with performances of the complete Beethoven Cycle at Alice Tully Hall in New York City, Stanford University, Los Angeles and the Smithsonian in Washington, D.C.

* * * * *

The American Musical Instrument Society announces the establishment of two prizes, to be conferred in alternating years, to publications that best further the Society's goal "to promote study of the history, design, and use of musical instruments in all cultures and from all periods": the Frances Densmore Prize for the most significant article-length publication and the Nicolas Bessaraboff Prize for the most distinguished book-length work. For the Densmore Prize (to be conferred in 1988 and in consecutive even years) the article-length work must have been published in English during calendar years 1985 or 1986. For the Bessaraboff Prize (to be conferred in 1989 and in consecutive odd years), the book-length work must have been published in English during calendar years 1986 or 1987. Each prize shall consist of the sum of $500. and a certificate. A committee of three will make the selection, which will be based upon qualities of originality, soundness of scholarship, clarity of thought, and contribution to the field.

Nominations (including self-nominations and the publications themselves) for the 1988 Densmore Prize for article-length works published during calendar years 1985 or 1986 should be submitted by March 1, 1987 to the committee chair: Professor Howard Mayer Brown, Department of Music, University of Chicago, 5845 South Ellis Avenue, Chicago, Illinois 60637. The prize will be announced at the 1988 annual business meeting of the Society and in the Society's Newsletter.

* * * * *

Arthur H. Methot (1905-1987) came to me in 1960 wanting to learn more about violin making so he could make an instrument for each of his 12 children - which he did, and more. He had studied violin at the Conservatory in Detroit, but could not continue because of a poorly healed broken arm. A native of New Hampshire, Methot's working career included many years as a shoemaker, and during the war years as a machinist at Pratt Whitney and later at the Amoskeag Lawrence Mills and finally as a fireman at the Notre Dame Hospital in Manchester, N. H., until his retirement in 1973. He was a knowledgeable woodsman and supplied us with Canadian curly maple as well as beautiful willow for blocks and liners for the Octet instruments, and some 1836 Spruce beams from a demolished hospital building.

It was Arthur and Raymond Methot, his son, a biochemist, who introduced our speaker / amplifier/ glitter technique for free plate tuning, which is now in use by violin makers around the world.

Carleen M. Hutchins

The CAS office has just received the two volume set of AKUSZTIKA by Professor Tamas Tarnóczy, retired Director of the Acoustic Research Laboratory of the Hungarian Academy of Sciences, who has received many international honors and is known worldwide for his research and writing in acoustics. He is a Fellow of the Acoustical Society of America and has been awarded the Hungarian Bekesy Medal, the Petzval Prize, the "Munka Erdemrend" Silver Medal and the French Academy Fellow Silver Medal. Tarnóczy also designs his own New Year's cards - one of which is reproduced here.

Drawing of Zoltán Tarnóczy

("The undesirable way of music..") Tamás Tarnóczy

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A. Askenfelt, "Stage Floors and Risers - Supporting Resonant Bodies or Sound Traps?" Acoustics for Choir and Orchestra, Royal Swedish Academy of Music No.52,1986

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Necrology

Harriett Bartlett, Cambridge, Mass.
Robert E. Fryxell, Cincinnati, Ohio
Arthur Methot, Manchester, N. H.
Thomas W. W. Stewart, Lambeth, Ontario, Canada
Samuel Wade, Phoenix, Arizona